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THE BANNOCK OVERTHRUST

A MAJOR FAULT IN SOUTHEASTERN IDAHO AND NORTHEASTERN UTAH

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INTRODUCTION

In the course of a detailed geologic examination of portions of the Phosphate Reserve in southeastern Idaho during 1911 and 1912, the writers have had an opportunity to study an overthrust

fault which appears to be of unusual extent and magnitude. The purpose of this paper is to summarize the stratigraphy of the region and describe a portion of the great fault.

EARLIER WORK

The first geologic report on the general region is that of Peale (18) of the Hayden Survey.[1] The stratigraphy of the region has been modified only to the extent naturally incident to a more detailed study, but the newly described structural feature is scarcely of the same character. It appears that the stratigraphic discordance produced by the great thrust was recognized by the relations shown between the Jura Trias and the Carboniferous on Peale's map. The accompanying text, however, does not make reference to it. The 1909 report on the phosphate deposits by Gale and Richards (10) noted the existence of major thrusts in the Montpelier and Georgetown districts, but not enough of the surrounding country had been mapped at that time to suggest the relationship between the two. C. L. Breger (6a) in the same year noted the existence of a similar thrust along the valley of Crow Creek east of Preuss Range. The 1911 report (19a) on a portion of the Phosphate Reserve described a thrust fault which extended through the region west of Bear Lake and north into Nounan Valley. It remained, however, for the 1911 fieldwork in adjoining areas to develop sufficient data for a clearer understanding of the character of the thrust faulting.

STRATIGRAPHY

The rock formations of southeastern Idaho, and the adjoining portion of Utah, comprise a stratigraphic section in which every system from Middle Cambrian to Upper Jurassic or possibly basal Cretaceous is present unconformably overlain by Tertiary and Quaternary deposits. The latter rocks toward the south are sedimentary, but toward the north include extensive basaltic flows which are probably in part as late as the early Quaternary.

In the vicinity of Ogden, Blackwelder (1) has noted the presence of the Algonkian and Archean, while to the east of the Wyoming border Veatch (24) and Schultz (20) have described additional

[1] The blackface figures in parentheses following a name refer to the Bibliography at the end of this paper.

members of the Cretaceous system. These portions of the geologic column do not outcrop within the area with which this paper especially deals and are not included in the generalized section which follows.

GENERALIZED SECTION IN THE REGION OF THE BANNOCK THRUST

	FEET
Quaternary: Alluvium, travertine, basalt flows	
Tertiary (Pliocene?): Marls, marly limestone, and calcareous conglomerates	
Tertiary (Eocene): Sandstones, conglomerates, and limestones	
Unconformity.	
Cretaceous and Jurassic:	
Beckwith formation (24h) (6a), red shales, sandstones, and conglomerates	4,650
Jurassic: Twin Creek limestone (24i) (shaly limestone)	3,500
Jurassic or Triassic: Nugget sandstone (dark red to white sandstone and quartzite)	1,900
Triassic: (4) (22) (23)	
Ankareh shale (a red-bed horizon) shales and mottled limestone	670
Thaynes limestone, thin-bedded sandy limestone with heavy limestones (and locally conglomerate at top?)	2,000
Woodside shale, iron-stained calcareous shale with heavy limestones at top	1,000
Carboniferous:	
Permian?	
Phosphoria formation, 75 to 627 ft., averages	350
Rex chert member, 0 to 450 ft	
Pennsylvanian:	
Wells formation	2,400
Mississippian:	
Limestone, upper Mississippian, light gray, thick-bedded	1,300
Madison limestone, lower Mississippian, thin-bedded, dark gray to bluish-gray	1,000
Devonian: Jefferson limestone (14a) (19b)	750
Silurian: Limestone (13) (19c) (1a)	400
Ordovician: (1c) (19c) Quartzite and limestone	1,450
Upper Cambrian: (25) (26) St. Charles limestone (bluish-gray to gray arenaceous limestones, with some cherty and concretionary layers, passing at the base into thin-bedded gray to brown sandstone	1,197
Middle Cambrian:	
Nounan limestone (light gray to dark lead-colored arenaceous limestones)	814

	FEET
Bloomington formation (bluish-gray, more or less thin-bedded limestones and argillaceous shales; small rounded nodules of calcite are scattered irregularly through many of the layers of limestone)	1,162
Blacksmith limestone (gray arenaceous limestones in massive layers)	23
Ute limestone:	
Blue to bluish-gray thin-bedded fine-grained limestones and shales, with some oolitic, concretionary, and interformational conglomerate layers	731
Spence shale member (argillaceous shales)	30
Langston limestone (massive-bedded bluish-gray limestone with many rounded concretions)	30
Brigham quartzite (massive quartzitic sandstones)	1,000

Two of the formation names, those of the Wells and Phosphoria formations, and the name of one subordinate member, the Rex chert, appear for the first time in the above table. A discussion of the application of these names and detailed descriptions of the beds to which they are applied follow.

PHOSPHORIA FORMATION

The name of the Phosphoria formation is derived from Phosphoria Gulch, which joins Georgetown Canyon at a distance of 2.5 miles N. 16° W. of Meade Peak, Idaho, in which the formation is typically exposed.

The name of the Rex chert member is derived from Rex Peak in the Crawford Mountains, Rich County, Utah, where the chert forms an anticlinal cap. This locality has been described by Gale (10a) and the selection of the name for the member was originally made by him.

The following section is complete and representative of the formation as exposed in the region about Phosphoria Gulch, Idaho.

COMPLETE SECTION OF PHOSPHORIA FORMATION, INCLUDING THE REX CHERT MEMBER, MEASURED IN SECTION 12, T. 10 S., R. 44 E., AND PHOSPHATE SHALES IN PROSPECT PIT IN SECTION 7 OF T. 10 S., R. 45 E.

Description	Thickness Ft.	In.
Shale, black, cherty, weathers red-brown to purple	80	
Chert, in heavily iron-stained ledges	60	

Description	Thickness Ft.	In.
Limestone, gray, banded with ashy gray to black chert..... (Thickness of Rex chert member 240 feet)	100	
Shale, dark brown, weathers light brown, not fetid.....	1	0
Phosphate rock, gray, coarsely oolitic, with large pebbles, fossils, or oolites near base, some up to 2 inches in diameter; phosphoric acid 36.3 per cent.....	1	0
Shale, brown, finely oolitic.....	0	5
Phosphate rock, gray, coarsely oolitic pebbles or oolites up to 1 inch in diameter; phosphoric acid 36.7 per cent	0	8½
Shale, brown, weathers gray, in part finely oolitic.....	0	2½
Clay, yellow, weathered sandy, concretions up to ¼ inch, 3 grades into above shale.....	0	8
Phosphate rock, brown, medium oolitic, weathers gray; phosphoric acid 35.3 per cent.....	0	5
Shale, dark brown, phosphatic.....	0	2
Phosphate rock, dark brown, weathers gray, medium oolitic, single bed; phosphoric acid 29.4 per cent.....	0	5
Shale, brown, sandy with concretions up to 1 inch.....	0	5
Phosphate rock, gray, coarsely oolitic; phosphoric acid 35.9 per cent.....	1	2
Shale, dark brown to black, finely oolitic.....	0	3
Phosphate rock, coarsely oolitic; phosphoric acid 35.9 per cent.....	0	4
Shale, brown, sandy.....	0	1
Phosphate rock, medium oolitic.....	0	1½
Shale, brown, weathers gray with bluish tinge, finely oolitic....	0	5
Phosphate rock, black, soft, medium oolitic.....	0	2
Shale, brown, calcareous.....	0	4
Phosphate rock, black, medium oolitic, soft.....	0	1
Shale, brown, oolitic in thin streaks.....	0	2
Phosphate rock, gray, coarse to finely oolitic; phosphoric acid 33.2 per cent.....	0	11
Phosphate rock, brown, finely oolitic, shaly.....	0	3
Phosphate rock, brown, medium oolitic.....	0	4
Shale, brown, with ¼-inch streak of oolitic rock near base.....	0	6
Phosphate rock, dark brown, coarse to finely oolitic, shaly in places; phosphoric acid 33.2 per cent.....	0	9
Phosphate rock, gray, coarsely oolitic, includes ½ inch of shale near base; phosphoric acid 37 per cent.....	1	1
Limestone, drab, impure.....	0	5
Phosphate rock, medium to finely oolitic.....	0	3

Description	Thickness Ft.	In.
Shale, brown, weathers gray	0	9
Phosphate rock, dark gray, coarsely oolitic, soft	0	2
Shale, brown	0	3
Phosphate rock, dark gray, coarsely oolitic, with several shaly partings less than $\frac{1}{8}$ inch thick; phosphoric acid 30 per cent	0	10
Limestone, lenticular	0	10
Phosphate rock, dark brown, medium to finely oolitic; phosphoric acid 26.1 per cent	9	8
Shale, black, in part finely oolitic	3	0
Shale, brown, partly weathered to clay	1	8
Shale, black, phosphatic, in part finely oolitic	6	6
Shale, brown, with concretions up to 2 inches in diameter	0	10
Shale, rusty brown to yellow, with a few concretions up to 1 inch in diameter	1	8
Shale, dark brown, with thin pebbly or concretionary bed at top, phosphatic in places	16	6
Pebbly or concretionary bed, concretions up to 2 inches in diameter	0	$3\frac{1}{4}$
Shale, brown	1	2
Shale, black to dark brown	0	9
Pebbly or concretionary layer, phosphatic	0	3
Shale, black, slightly oolitic	0	7
Shale, with pebbles or concretions up to 2 inches in diameter	0	6
Shale, brown, weathers to ochreous soil	3	4
Pebbly or concretionary bed	0	4
Shale, brown, weathers to ochreous soil	2	3
Pebbly or concretionary bed, phosphatic	1	0
Shale, brown, phosphatic	2	6
Shale, black, thin-bedded	0	6
Clay, ochreous	0	10
Shale, brown	1	0
Shale, black to light brown, slightly phosphatic	11	0
Limestone, broken, and intermixed with shale	6	0
Shale, broken, and weathered, only slightly phosphatic	21	0
Shale, black, phosphatic, finely oolitic, estimated to contain phosphoric acid 20 per cent	5	6
Shale, brown, weathers yellow, concretionary	1	0
Limestone, purplish-drab, lenticular	0	8
Shales, dark, broken, and weathered	15	0
Phosphate rock, broken, weathered drab	3	0
Soil, black, fetid	9	0

Description	Thickness Ft.	In.
Shale, black, phosphatic, finely oolitic	5	6
Limestone, dark, fetid	0	6
Shale, brown, somewhat phosphatic, contorted	15	0
Limestone, dark gray, dense ("Cap Lime" fossils)	3	0
Phosphate rock, dark brown, medium oolitic, soft, broken, apparently high grade*	7	0
Shale, brown, contorted, soft	1	0
Sandstone, white, calcareous, weathers buff. Top of Wells formation		
Thickness of phosphate shales	175	2½
Thickness of formation	415	

*Corresponds to bed from which sample 144S was taken. (10c)

The Phosphoria formation is the equivalent of the upper two members of the Park City formation (4a) (10b) as heretofore mapped in the phosphate district of Idaho and Utah, namely, the "overlying chert" and the phosphate shales. These members have also been recognized in the type section (4a) of the Park City in Cottonwood Canyon by H. S. Gale,[1] who reviewed the section in 1909 and noted the presence of phosphate rock. Gale regards the upper 129 feet of Boutwell's section (4a) as approximately equivalent to the chert member, and the underlying 112 feet as representing the phosphatic shale interval.

The remaining 194 feet is predominantly siliceous but contains a number of prominent limestone beds and is evidently comparable to the underlying siliceous limestone or calcareous sandstone of the phosphate districts.

The Park City formation was first referred by Boutwell to the Pennsylvanian, but in his later work on the district (5) has been referred as a whole doubtfully to the Permian. The lower portion contains the bonanzas for which the Park City district is famous and is therefore the essential part of the formation. This member is now upon additional faunal evidence referred to the Pennsylvanian.

The Phosphoria formation is also correlated with the upper portion of the Embar formation of Wyoming (8a) (9a) (3a), and

[1] Personal communication.

the phosphatic beds above the Quadrant formation of certain areas (11) (1) in southwestern Montana.

The Rex chert member is the conspicuous portion of the Phosphoria formation, and because of its superior hardness it stands out in salient topographic features. The phosphate shales on the other hand are comparatively non-resistant and the development of gulches along them is characteristic.

Locally 50 to 75 feet above the base the Rex chert gives way to gray limestone and in other places a dark gray to black or purplish flinty or cherty shale occupies the major portion of the Rex chert interval, but more generally the shaly facies is present near the top of the section and is occasionally with difficulty distinguished from the basal portion of the Woodside shale.

The Rex chert is generally non-fossiliferous but locally contains sponge spicules and casts of crinoid stems. Dr. Girty lists the following as the most characteristic species:

Productus multistriatus
Productus subhorridus
Spirifer aff. cameratus
Spiriferina pulchra
Composita subtilita var.

At a locality on Deer Creek in the Preuss Range Dr. Girty obtained the following fauna from the limestone facies of the Rex chert:

Amphoporella laminaria
Productus nevadensis
Productus eucharis
Productus multistriatus(?)
Camarophoria n. sp.

The basal portion of the Phosphoria formation consists of 75 to 180 feet of yellowish to brown phosphatic sandstones and shales with 1 to 3 economically important beds of rock phosphate, and occasional dark fetid limestones in beds and lenses ranging from 3 inches to 2 feet in thickness.

The fauna of the phosphate shales is an extensive one and has

been studied by Dr. Girty, who has selected the following characteristic list from his bulletin (**12**) on the subject:

Lingula carbonaria (?)
Lingulidiscina missouriensis
Chonetes ostiolatus
Productus geniculatus
Productus eucharis
Productus montpelierensis
Productus phosphaticus
Pugnax weeksi
Pugnax osagensis var. occidentalis
Ambocoelia arcuata
Leda obesa
Plagioglypta canna
Omphalotrochus ferrieri
Omphalotrochus conoideus
Hollina emaciata var. occidentalis

The distribution of the Phosphoria formation, so far as at present known, is limited to portions of southeastern Idaho, northeastern Utah, and western Wyoming.

WELLS FORMATION

The Phosphoria formation is normally underlain by 2,400 feet of sandy limestones, calcareous sandstones, and quartzites of somewhat variable character. These beds are here grouped in a formation whose name is derived from Wells Canyon in T. 10 S., R. 45 E., on the north side of which a detailed section was measured. The stratigraphic interval is probably the same as is represented by the Morgan, Weber, and a portion of the Park City formations of northeastern Utah. In the Idaho field, however, these rocks show such variable lithologic features that it has been found impracticable to apply successfully the names Weber and Morgan over a major portion of the area. Furthermore, Dr. Girty comments that there is no faunal assurance that these divisions as recognized are actually the equivalents of the formations in Weber Canyon, Utah. Faunal and structural grounds make it advisable to include

in the formation the limestone that normally underlies the phosphate shales and has hitherto been included in the Park City formation (10b) (19d).

The following section was measured at the type locality.

GEOLOGIC SECTION OF BEDS EXPOSED ON NORTH SIDE OF WELLS CANYON, IDAHO

WELLS FORMATION

	FEET
(1)	
Limestone, light brownish-gray, sandy *Squamularia* or *Composita*, possibly *Productus* crinoid stems	5
Chert, bluish-gray	1
Limestone, light brownish-gray, sandy	44
(2)	
Concealed	172
Sandstone, gray, calcareous, fine-grained in loose blocks and thin beds of quartzite or chert	150
Concealed	50
Sandstone, whitish, soft, in loose blocks, weathers like limestone, includes small quartz-lined geodes, poorly exposed, and partly represented by sandy soil and small fragments	350
Limestone, light bluish-gray, earthy with considerable dark chert	230
Sandstone, yellowish to red, in large blocks weathered rounded	100
Sandstone, whitish, rather soft	150
Quartzite, white, weathers pink to red, in large loose slabs, laminated and cross-bedded	200
Limestone, in part clear, in part cherty	200
(3)	
Limestone, dark gray with large chert concretions, fossil collection No. 45	200
Limestone, sandy, alternating with quartzite and clearer limestone	400
Sandstone, whitish, fine-grained, one bed	2
Sandstone, red in part, nearly quartzite, cross-bedded	100
Limestone, sandy, with quartz-lined geodes, one bed	3
Sandstone, white to reddish, soft, bears abundant *Schizophoria;* also represented by fossil collections Nos. 28 and 32 for near-by locality	35
Sandstone, one bed	2
Sandstone, thin-bedded; fossil collection 101c	6
Total thickness, Wells formation	2,400

UPPER MISSISSIPPIAN

	Feet
Limestone, earthy with chert in irregular concretions and streaks parallel to bedding	20
Limestone, light gray to whitish, thin-bedded; fossil collection 101	46
Sandstone, white, calcareous, bears large *Zaphrentoids*	14
Limestone, dark gray crinoidal, includes a *Martinia* horizon, about	100
Shale and reddish quartzite fragments, about	30
Quartzite, whitish, outcrops small and scattered, bears small *Zaphrentoids*	270
Concealed	200
Limestones, gray, in 1- to 3-foot beds, fossil collections	450
Base of upper Mississippian not exposed.	
Thickness of upper Mississippian exposed	1,130
Total thickness of section	3,530

It will be noted that in this section it is possible to subdivide the Wells formation into three portions, an upper calcareous sandstone or siliceous limestone, a middle sandy series, and a lower sandy and cherty limestone series, the lower two of which, however, do not correspond with the Weber and Morgan formations in Weber Canyon, Utah. Dr. Girty has recently reviewed the section at the latter locality and states that the order of lithologic succession is quartzite, calcareous sandstone, and red quartzite.

The variations which occur in the three portions of the Wells formation have been studied throughout the general area under discussion and in brief are as follows:

The upper limestone ranges from a maximum thickness of 75 feet down to a feather edge. It consists of a dense gray calcareous sandstone grading locally to siliceous limestone, which weathers into white massive beds that are topographically conspicuous as cliff makers. Bluish-white chert occurs in it in bands 2 inches to 1 foot thick and locally in ovate nodules. Toward the base the chert becomes more nodular and darker. Silicified fragments of brachiopods project in little crescents from the weathered surfaces of the limestone. This member is usually sparingly fossiliferous but, in the vicinity of Swan Lake, Dr. Girty reports a limited fauna (12*a*).

Local unconformity.—Locally the upper cliff-making limestone (1) is absent from the section and the Phosphoria formation then rests directly upon the more siliceous portion of the Wells formation, which in these places is composed of a breccia of chert and quartzite, similar to that described by Blackwelder (1d) under practically identical conditions, and it appears to the authors that this relationship represents another instance of a brief erosion interval in this part of the geologic section. Dr. Girty says (personal letter):

> The upper part of the Wells formation is usually nearly barren of fossils. Occasionally large *Producti* of the *semi-reticulatus* group are found as at Station 49 (T. 9 S., R. 45 E., sec. 35 SW ¼ SE ¼); rarely, however, in identifiable condition. Some well preserved examples obtained at this horizon near Swan Lake (Bannock County) show a form closely allied to *Productus Ivesi.* In that region also a small spiriferoid is very abundant, occurring as silicified fragments which project from weathered surfaces like small arched scales. When they can be identified these fossils belong to a species of *Squamularia* related to *S. perplexa.*

The middle portion (2) comprises 1,700 to 1,800 feet of sandy limestone with occasional thin beds of quartzite and sandstones, weathering white, red, or yellow, and forming smooth slopes with few projecting ledges. This portion is sparingly fossiliferous or non-fossiliferous. No fossils have yet been found in it. Locally a siliceous facies becomes strongly developed and this portion is then comparable with the Weber quartzite of Utah.

In the section under discussion sandy and cherty limestones with thin interbedded sandstones are conspicuous in the lower portion (3) of the Wells formation. The maximum observed interval of beds included in this facies is about 750 feet. Within a distance of 2 miles to the north the same interval was found on careful study to comprise only about 100 feet of beds. The cherty limestones are topographically important as ledge-makers and carry a fauna which, according to Dr. Girty, is probably similar in age to, although not specifically identical with, that found in the Morgan formation of Utah. Blackwelder (1e) has described the Morgan formation as composed of red sandstone, shale, and thin intercalated limestones, so that, lithologically, it is wholly distinct from the cherty limestones described above. Dr. Girty has con-

tributed the following faunal lists of collections from the Wells formation together with the following comments:

At the very base of the Wells formation a *Schizophoria* is often very abundant, apparently the same species as White identified in New Mexico as *S. resupinoides*? (Lot 101c). A short distance above a more varied fauna is usually found in which a large variety of *Spirifer rockymontanus*, the same which I identified in Colorado as *S. boonensis*, is specially abundant (Stations 28 and 32). Large branching *Stenoporas* related to *S. carbonaria* are also a feature of this fauna. Another phase of the lower Wells fauna is shown in Lot 33. In this assemblage of species *Marginifera splendens* is extremely common and large branching *Stenoporas* are also plentiful.

Lot 33

T. 9 S., R. 45 E., sec. 22, SW corner. From beds about 500 feet above base of Wells formation.

Stenopora Wellsiana
Stenopora gracilis
Stenopora Idahoensis
Stenopora ? sp.
Derbya sp.
Productus Cora
Productus Nebraskensis
Productus semireticulatus
Marginifera splendens
Spirifera rockymontanus

Lot 45

See section.

Zaphrentis Gibsoni
Monilipora Prosseri
Rhombopora lepidodendroides
Productus Cora
Productus semireticulatus
Spirifer cameratus
Composita subtilita
Euconospira n. sp.

Lot 28

T. 9 S., R. 45 E., sec. 35, SE ¼.

Spirifer rockymontanus
Myalina aff. Kansasensis
Aviculopecten sp.

Lot 32

Same locality as Lot 28 but from beds about 150 feet lower in the section.

Stenopora Idahoensis
Stenopora ? sp
Batostomella ? sp.
Derbya sp.
Productus Cora
Spirifer rockymontanus
Composita subtilita
Myalina sp.

Lot 101c

See section.

Schizophoria resupinoides?

UPPER MISSISSIPPIAN LIMESTONE

The Wells formation in southeastern Idaho rests in apparent conformity upon limestone of upper Mississippian age. In Utah, however, Blackwelder (1f) has observed an unconformity at this position in the section. These limestones represent an unnamed formation comprising about 1,130 feet of beds. Lithologically they are massive gray, light to dark colored, weathering white to light gray. Locally a dark shale zone is developed near the top about 15 feet thick. In places also chert nodules with concentric and irregular forms and streaks of chert are present. The limestones are sometimes specked with siderite and seamed with calcite or aragonite, and are abundantly fossiliferous in some horizons. The fauna includes large cup corals with many fine septa, *Syringopora*, *Lithostrotion*, *Martinia*, and *Productus giganteus*. The Martinias are found in a bed near the top of the formation. A fauna collected at Ross Fork–Lincoln Creek (Idaho) by Meek (17) and later by Girty (19e) at Swan Lake which is comparable to that of the Spergen limestone of the central basin region of the United States is included at the Swan Lake locality in the upper Mississippian limestone interval.

The formation constitutes much of the Preuss Range and is well exposed in Meade Peak, the culminating point of that range. No complete section has been measured because of structural interruptions, but it is expected that future studies in the Ross Fork locality may afford a more favorable opportunity to obtain this, and the selection of a type locality for the formation is deferred for the present.

The authors are also indebted to Dr. Girty for the following faunal list and comments:

> An interesting and varied fauna has in places been obtained from the upper part of the upper Mississippian. It is shown by the list of forms collected at Station 101. A short distance below this collection a new species of *Martinia* was found in countless numbers constituting a bed a foot thick. Very abundant also in local occurrences is a small variety of *Productus giganteus*. Large Zaphrentoid corals are likewise a feature of the upper Mississippian, often occurring associated with *Syringopora* and one or more species of *Lithostrotion*. These colonies are sometimes of great size. Here too is sometimes found an

assemblage of small forms more or less related to the "Spergen" fauna reported by Meek from Ross Fork. The horizon of all these rather strikingly different facies appears to be below that of Station 101.

101

Zaphrentis sp.	Edmondia ? sp.
Stenopora sp. a	Conocardium sp.
Stenopora sp. b	Schizodus sp.
Stenopora ? sp.	Sphenotus sp.
Batostomella ? sp.	Myalina aff. Sanctiludovici
Rhombopora ? sp.	Leptodesma aff. Spergenense
Productus semireticulatus	Sulcatipinna Ludlowi ?
Productus semireticulatus var.	Parallelodou ? sp.
Productus pileiformis	Cypricardinia ? sp.
Productus punctatus var.	Aviculipecten sp. a
Productus aff. longispinus	Aviculipecten sp. b
Diaphragmus elegans	Aviculipecten sp. c
Camarophoria Wortheni	Pseudomonotis ? sp.
Dielasma sp.	Laevidentalium venustum ?
Spirifer striatus ?	Naticopsis sp.
Spirifer increbescens ?	Straparollus similis var.
Spiriferina sp.	Bulimorpha aff. elongata
Composita trinuclea ?	Griffithides sp.
Edmondia sp.	Phillipsia sp.

THE BANNOCK FAULT

The field seasons of 1909 and 1910 led to the recognition by members of the U.S. Geological Survey of important thrust faults in southeast Idaho (10d, e) and adjacent parts of Utah (10f, g). In 1911 the study of the great fault east of Georgetown, Idaho, led to the view that several of these faults, formerly considered distinct, are in reality parts of one great overthrust, for which the name Bannock is proposed, from Bannock County, Idaho, where the fault is strikingly developed. The individual faults which have been thus united and the facts upon which the interpretation rests are described below (Fig. 1).

GEORGETOWN FAULT

In 1909 a thrust fault involving the superposition of Mississippian limestones upon rocks of Jurassic or Cretaceous age was recognized by Gale (10d) in Georgetown Canyon about 5 miles

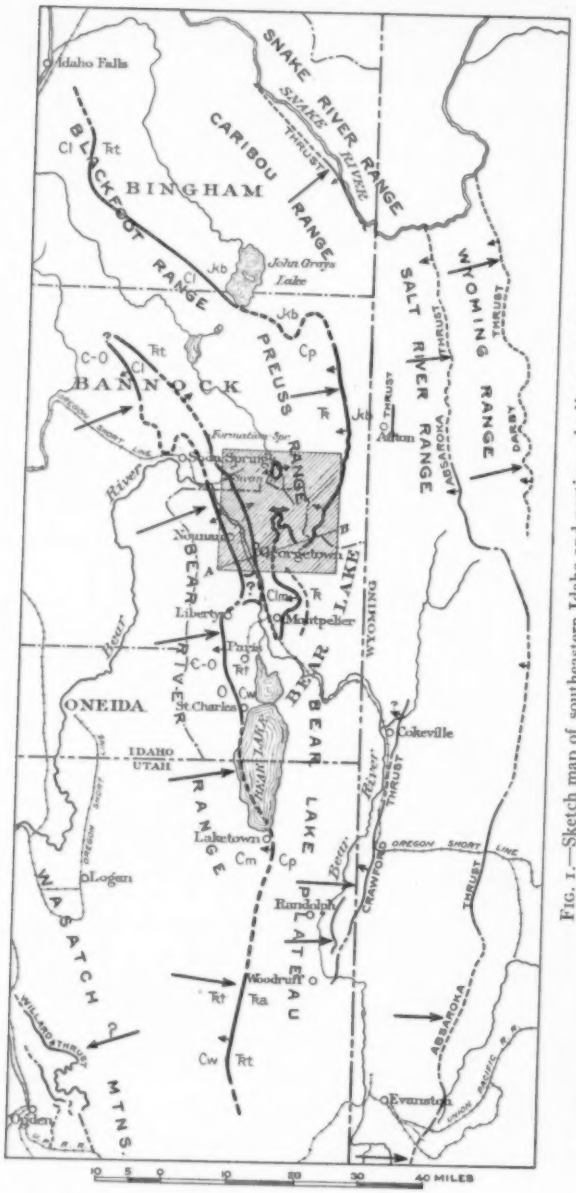

FIG. 1.—Sketch map of southeastern Idaho and portions of adjacent states.

Explanatory notes.—The trace of the Bannock thrust is shown by the heavy broken line. The shaded area is more fully illustrated by the stereogram, Fig. 2, and the geologic structure along the line *A–B* is represented by Fig. 5. The letter symbols signify as follows: *Jkb*, Beckwith formation; *Jlc*, Twin Creek limestone; *Tr*, Triassic undifferentiated; *Trn*, Nugget sandstone; *Tra*, Ankareh shale; *Trl*, Thaynes limestone; *Cp*, Phosphoria formation; *Cw*, Wells formation; *Cl*, Upper Mississippian limestone; *Cm*, Lower Mississippian (Madison) limestone; *Clm*, Mississippian undifferentiated; *O*, Ordovician; *C*, Cambrian.

northeast of the village of Georgetown (see map). In 1911 this district was visited by the writers and the fault was studied and mapped in greater detail. From the north fork of Georgetown Canyon, where the fault emerges from beneath the late conglomerates, its sinuous course was followed across the Preuss Range into Crow Creek as far as the mouth of Sage Creek (Fig. 2), a distance of approximately 30 miles, and here it appeared to continue northward.

The sinuosity of the fault trace is due not only to erosion but to deformation as well. In the north fork of Georgetown Canyon an anticlinal axis has arched the thrust surface or plane so that it has been partly removed and the underlying Nugget and Twin Creek formations are exposed in the valley, while long strips of heavy Mississippian limestone reach down the spurs of the ridges like the fingers of some giant hand (see Figs. 1 and 2). A synclinal axis depresses the thrust surface where it passes beneath the Preuss Range in the headwaters of Montpelier Creek. In this region there is a marked contrast between the massive and castellated limestones of the Mississippian that constitute the upper part of the ridge and the chippy and shaly limestones of the Twin Creek formation that are exposed along the lower slopes of the valley side.

In Georgetown Canyon and southeast across the Preuss Range (Fig. 3) the same relations obtain. The underlying Twin Creek beds are folded so that the stratigraphic throw cannot be obtained with accuracy, but the missing formations, including Pennsylvanian to Triassic (?) rocks (Nugget), represent a minimum vertical displacement of about 8,500 feet. Eastward the throw apparently diminishes partly by the agency of branching faults and partly on account of the folded structure of the rocks in the upper block.

The general trend of the trace of the fault appears to be a few degrees to the west of north and the direction of thrust a little to the north of east. The dip of the fault surface gives little aid in determining the direction of movement because of its present deformed condition. The older rocks, however, lie to the west and the thickness of the thrust block appears to increase in that direction.

The distance, perpendicular to the general trend, between the

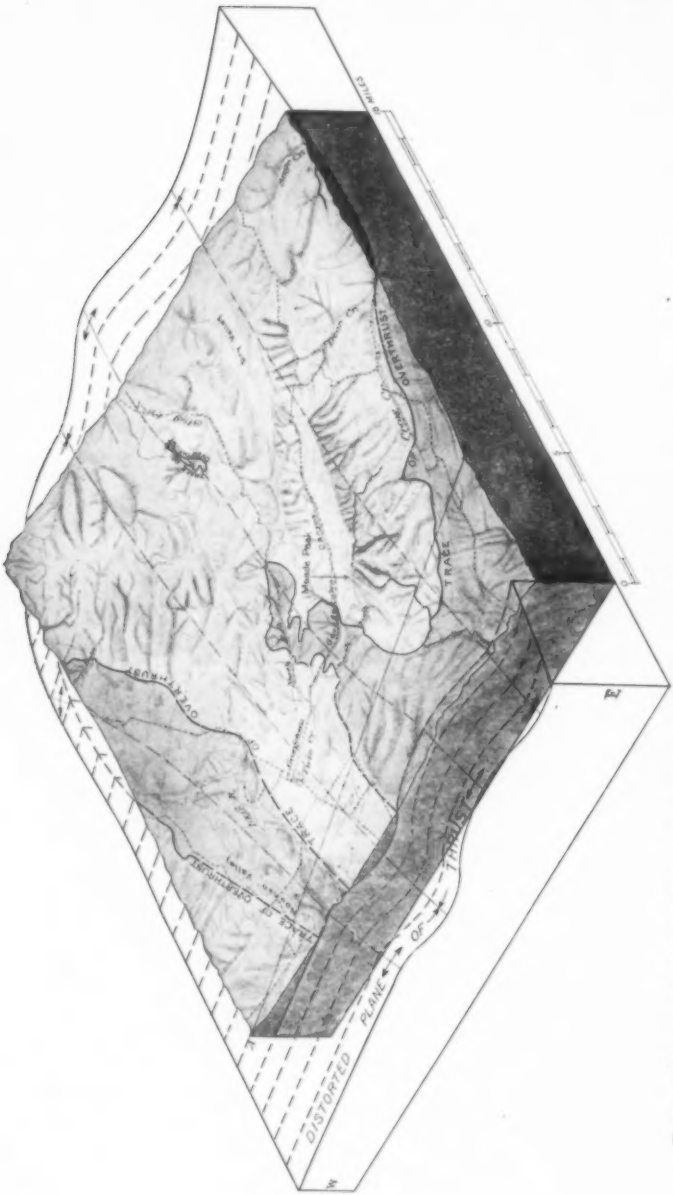

FIG. 2.—Stereogram of a portion of the region including the trace of the Bannock thrust. The location of the area is shown on Fig. 1. The direction of movement was in general from west to east and approximately parallel to the line of the structure section *A–B*.

westernmost observed portion of the fault trace in Georgetown Canyon and the easternmost portion of that trace in Crow Creek is about 12 miles. It appears, therefore, that the heave may be equal at least to that distance.

In the ridge west of Slug Creek (Fig. 2) an elongate area apparently surrounded by a fault boundary is interpreted as an anticlinal portion of the main thrust, or of a subordinate thrust, unroofed by erosion so that the underlying block is exposed through a "window" or "fenster." The position of this window with reference to the anticline in the north fork of Georgetown Canyon is favorable to this interpretation.

FIG. 3.—Panorama from south-pointing spur on hill north of Georgetown Canyon (see Fig. 2) looking northeast to nearly due south. Meade Peak is situated to the left of the middle of the picture. The trace of the Bannock thrust and a sharp drag fold in the overthrust Mississippian limestone is shown in the left foreground. The trace of the Bannock fault is also indicated on the divides between Georgetown and South Canyons, the latter and Dunn's Canyon; thence to the head of the latter where it crosses to the head of Montpelier Creek where it appears in Fig. 4. For explanation of letter symbols, see Fig. 1.

JOHN GRAYS LAKE AND BLACKFOOT FAULTS

Reconnaissance by the senior author and Dr. A. R. Schultz of the U.S. Geological Survey northward from the area above described and in the vicinity of John Grays Lake developed the presence of a thrust fault of similar magnitude in that region. While this fault has not been traced directly into the Georgetown fault, from the position of the thrust and its general relations it is interpreted as a continuation of that fault. The northwestward extension of the John Grays Lake fault is concealed by flows of basalt. A similar thrust was recognized in the same reconnaissance in the Blackfoot Range. The alignment and the

effects of the two are practically identical and they clearly may represent the same crustal break.

MONTPELIER FAULT

The work of Gale and Girty in 1909 (10e) in the Montpelier district demonstrated the existence near Montpelier of a great thrust fault in which heavy Mississippian limestones from the west were overthrust upon Lower Triassic formations, the Woodside, Thaynes, and Ankareh. Northward, southward, and westward the fault trace passes beneath the cover of late deposits. To the south no further indication of thrust faulting has been recognized on the east side of Bear Lake Valley, though a normal fault of considerable importance lies along the east shore of Bear Lake. To the north, however, at no great distance lies the Georgetown thrust fault, in which the structural relations of older and younger rocks are closely similar to those of the Montpelier district. There seems therefore good reason for the supposition that the two faults are continuous beneath the covering of alluvium and Tertiary deposits.

SWAN LAKE FAULT

In 1910 the writers found a thrust fault along the west base of the Aspen Range east of Bear Lake Valley, particularly well developed near Swan Lake, about 7 miles southeast of Soda Springs (Fig. 1). Here similar conditions hold and Carboniferous limestones lie upon Triassic rocks. The dip of the fault plane here appears to be eastward but this feature may, as in the Georgetown block, be due to deformation of the fault plane, for the source of the older rocks appears to be to the west as in the Georgetown fault. The trace of the Swan Lake fault is marked by the occurrence of sulphur and calcareous springs and also by great deposits of travertine, of which Formation Spring, 3 miles northeast of Soda Springs, with its basins and terraces is a beautiful example. In the 1910 report (19f) it was argued that these springs marked the trace of a normal fault that cut the Carboniferous thrust block along the west base of the Aspen Range. In the light of the later studies in the Georgetown region it seems probable that all the features ascribed to the normal fault can be better explained by the deforma-

tion of the thrust fault surface here described. Southward deposits of travertine occur at intervals along the base of the range to a point opposite the mouth of Three Mile Creek, about 3 miles south of Georgetown. It seems probable therefore that the Swan Lake fault is closely related to the Georgetown fault and may represent a part of the same thrust plane so deformed as to constitute the west limb of a gentle syncline. This interpretation is shown on the map and stereogram (Figs. 1 and 2).

WEST BEAR LAKE FAULT

In 1910 the writers encountered a great thrust fault on the west side of Bear Lake near Paris. This fault was followed southward beyond St. Charles, and northward beyond Soda Springs, a distance of over 45 miles (Fig. 1). The fault surface or plane appears to dip gently west. The upper block comprises rocks of Cambrian to Devonian age, while the underlying rocks are Pennsylvanian Lower Triassic (Upper Wells to Thaynes). Hence the structural relations here are similar to those of the Georgetown–Swan Lake fault except that the range of the formations involved and the magnitude of the throw are somewhat greater. The presence of two such great and similar overthrusts upon opposite sides of Bear River Valley, together with the known fact of deformation in the eastern fault, leads to the interpretation that the West Bear Lake fault and the Georgetown–Swan Lake fault are parts of the same great thrust fault, and that they have been separated by the partial erosion of an anticlinal fold in the thrust plane (see map and stereogram, Figs. 1 and 2).

FAULTS NEAR LAKETOWN AND WOODRUFF, UTAH

In 1909 Gale and Richards reported the existence of thrust faults at Laketown (10f) and near Woodruff (10g), Utah. These faults also represent movements from the west and bring rocks of Mississippian or greater age over younger formations. It is not possible to follow these faults and to trace their connection with each other and with the West Bear Lake fault to the north because of the extensive development of Tertiary beds (Eocene) in the intervening area. Their position and structural relations lend support to the view that they represent the southern continuation

of the great thrust fault to the north. This interpretation is tentatively shown on the map (Fig. 1).

MAGNITUDE OF THE BANNOCK FAULT

The trace of the Bannock fault as above constituted with its major sinuosities as represented on the map (Fig. 1) extends approximately 270 miles from the vicinity of Woodruff, Utah, to the region north of John Grays Lake. The general trend of the fault trace is slightly west of north and the direction of movement must have been perpendicular to that trend and, as indicated in the above discussion, was probably from the west.

The structure of the underlying block, as shown in the mountainous portion of the region, comprises a series of folds, for the most part close and overturned toward the east. Figs. 4 and 5 (photo and cross-section) show folds in the overridden Twin Creek limestone in the upper waters of Montpelier Creek. The large alluvial area at the north end of Bear Lake Valley and extensive areas masked by Tertiary detrital deposits render the structure of the underlying rocks problematical. This structure must, however, be determined before the place of origin and the amount of displacement effected by the thrust can be satisfactorily determined. It has been pointed out that in the Georgetown Canyon region the missing formations indicate a minimum vertical displacement in that locality of about 8,500 feet. On the west side of Bear Lake where Cambrian or Ordovician quartzites overlie Woodside and Thaynes formations the minimum throw on the same basis would probably be at least 12,000 feet.

The structure section (Fig. 5) along the line A–B contains one of the best exposures of the underlying block and a minimum amount of cover. The section represents the supposed attitude of the deformed fault plane.

Cambrian rocks nowhere rise to the level of the fault surface in the region traversed by the section. It therefore follows that the Cambrian portion of the overthrust block at the extreme west end of the section must have been derived from a fold lying to the west of this point, the structure of which is concealed by the overthrust block.

A clue to the minimum horizontal displacement is suggested by the possibility that the Mississippian limestones of the western

fold of the structure section may represent the source of the overthrust mass of these formations that lies some 12 miles to the east. The source can certainly not be nearer, for the Mississippian limestones do not rise to the level of the fault plane in any of the folds farther east in this district. Furthermore, the size of the Mississippian limestone mass, as inferred from known conditions north and south of the line of the section, suggests that either the westernmost fold of the section has not been made large enough, or that the source was a more westerly fold. These considerations make it apparent that the amount of horizontal displacement is not less than 12 miles.

Another measurement of the horizontal displacement may be expressed by a line drawn perpendicular to the general trend of the fault trace and extending from the westernmost point on the trace

FIG. 4.—Panorama from point near the southeast corner of area shown in Fig. 2. The direction of view is northwesterly. The southern tip of the uneroded portion of the overthrust block and the position of the subordinate branch fault, together with the approximate character of geologic discordance is indicated. A syncline and parallel anticlines are visible in the foreground (in the Twin Creek limestone). For meaning of letter symbols see Fig. 1.

to the easternmost point on the east margin of the fault block. The length of such a line is about 35 miles. This, however, neglects the recession produced by erosion along the east margin of the fault block.

AGE OF THE THRUST

The youngest rocks involved in the faulting are sandstones of the Beckwith formation, which may in part be of early Cretaceous age. The oldest rocks which have been found concealing its trace are the conglomerates of the Almy formation (24a) which represents the basal portion of the Wasatch group as defined by Veatch.

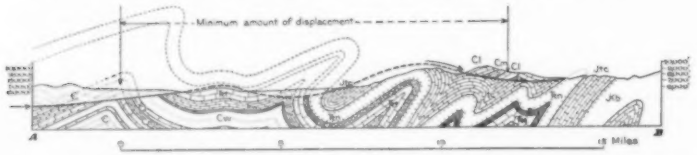

FIG. 5.—Geologic structure section along the line *A–B* in Figs. 1 and 2. The meaning of the letter symbols is explained under Fig. 1 with the exception of *Trw*, which represents Woodside shale.

The possible range of age is then from late Cretaceous to early Eocene, and it is probable that the faulting may have occurred during the interval represented by the unconformity between the Adaville (24b) and Evanston (24c) formations of Veatch.

DEFORMATION OF FAULT PLANE

The arrow points distributed along the fault trace on the map (Fig. 1) indicate in a general way the present attitudes of the fault plane. The stereogram (Fig. 2) shows the nature of these folds as present and reconstructed for a block 18 miles square. The location of Fig. 2 is indicated by the shaded area on the map, Fig. 1. The plications comprise two anticlines, two synclines, and portions of the adjoining folds. The trend of these folds is slightly west of north. Erosion has completely unroofed the western anticline and has made a considerable start on the second. The exposure of a closed area of the underlying block through a "window" or "fenster" in the overthrust has already been mentioned.

Deformation of fault planes is usually attributed to a renewal of the compressive forces and the folding tends to continue along

the lines formerly developed. In the vicinity of Meade Peak near the south end of the Preuss Range, where the best opportunity has been found to study the character of the deformation, a well defined syncline has been developed almost directly under a sharp anticline in the overlying beds. The question is raised as to whether or not the deformation of the plane of the thrust may be due to the load of the overlying anticlinal mass rather than lateral pressure. The dip of the fault plane that branches from the main fault and extends under the east flank of Meade Peak (Fig. 4) is steep and in places appears to be inclined westward. These facts are regarded as unfavorable to the latter view.

PARALLEL ASSOCIATED THRUSTS

Extensive overthrust faults are by no means a novel feature of the region, and faults have been previously described immediately east and west of the trace of the Bannock. The position of these faults has been shown upon Fig. 1.

Western Wyoming.—Peale (18a), Veatch (24d), and Schultz (10a) have described portions of the great Absaroka thrust, the trace of which lies about 8–25 miles east of the state boundary.

The throw in two localities (24e) described by Veatch is over 15,000 and 20,000 feet respectively. In the latter place rocks of Triassic age rest upon rocks of middle Cretaceous age—specifically, the Thaynes limestone upon the Oyster Ridge sandstone member of the Frontier (24f) formation.

North of these areas Schultz reports that the throw is of the same amount. The Darby, another overthrust which has been mapped by Schultz (20b), has a maximum exposed horizontal displacement of 3 miles. Labarge Mountain, which is a part of the overthrust block overlying the plane of the Darby fault, is composed in part of rocks of Cambrian age. This is, according to Schultz,[1] the easternmost exposure of the Cambrian rocks which make up the greater part of the Bear River Range in Utah and Idaho, a distance of over 50 miles to the west. It is possible, then, that the rocks present in Labarge Mountain may have been derived from the region of the Bear River Range.

[1] Personal communication.

Between the Absaroka and Bannock thrusts there appears to be at least one extensive parallel thrust zone. The Crawford thrust (24g) or the parallel fault (10h) immediately to the west may represent the southern end, while the faults reported in the vicinity of Cokeville (10i), Afton (18b), and observed by the senior author and A. R. Schultz in the Snake River region, represent the northward continuation.

These overthrusts are held by Veatch (24) and Schultz (20) to have occurred near the close of the Cretaceous period.

Ogden, Utah.—In the vicinity of Ogden, Blackwelder (1) has recently described several overthrusts. The major of these, the Williard thrust, causes lower Algonkian slates and graywackes to overlie Cambrian and Carboniferous sediments. The thrust plane has an average easterly dip of 15° but locally is as high as 50°. Blackwelder holds that subsequent deformation of the plane has been slight and that the apparent distortion is mainly due to original undulation. The maximum exposed horizontal displacement of 4 miles is probably only a small fraction of the total heave. The direction of movement is naturally inferred to be westward from the inclination of the thrust plane. The writers suggest that broader regional studies are necessary before a westward direction of movement can be regarded as proved. It may well be that the present eastward inclination of the fault plane is the result of deformation, as is clearly the case in many places along the trace of the Bannock thrust.

Blackwelder described two other thrusts in the Ogden region, one which produces discordant relations within the Cambrian, and another which causes Carboniferous limestone to overlie Cambrian shales and quartzites.

Blackwelder concludes that the Ogden thrusts "are of Cretaceo-Eocene age."

RELATION OF BANNOCK THRUST TO PARALLEL THRUSTS

The fact that the several portions of the Bannock thrust as described have been isolated by erosion and disguised by subsequent deformation makes it possible that future study will show that outliers of the overthrust block lie to the east of the margin of the Bannock thrust as at present defined.

The additional possibility should not be overlooked that the known thrusts of probably identical age lying to the east and to the west may in reality bound portions of the same overthrust mass which have been isolated by erosion.

North of the region of the Bannock thrust and in what appears to be the same zone of crustal readjustment, faults of great magnitude are known to exist. One in Montana, on the east side of the Bitterroot Mountains, has been described by Lindgren (**15**), another in the vicinity of Philipsburg, Montana, by Calkins (**7**), and the Lewis thrust in northern Montana and southern British Columbia which has been described by McConnell (**16**), Willis (**27**), and more recently studied by Campbell.

The last two are clearly thrusts the planes of which have been deformed, and all three may eventually prove features of the same tectonic event as the Bannock and the parallel faults toward the south, although it appears that if Willis' age determination of the Lewis thrust is correct, the Bannock overthrust occurred at an earlier geologic date.

It is apparent, however, that a close approximation of the actual and relative ages of the several faults awaits more extended geologic studies in the Rocky Mountain region.

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GLACIATION IN THE TELLURIDE QUADRANGLE, COLORADO

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PART III

DESCRIPTION OF DEPOSITS OF EARLIER DRIFT

RIDGES EAST AND WEST OF EDER CREEK

On the east side of Eder Creek, from the edge of the southern part of the ridge down to within 200 or 300 feet above the stream, and thence northward in an irregular belt a quarter of a mile or less from the stream, the surface shows plentiful bowlders up to 15 feet in diameter. These large bowlders are mostly rather rough and angular, and consist chiefly of Potosi rhyolite or Silverton, and Telluride. On the top of the ridge, the deposit contains fewer bowlders at the surface, their size is on the average less, and a greater variety of rocks is included—San Juan being noticeably more abundant than on the slope to the west. A striated bowlder was found on the top of the ridge at 10,500 feet. Farther north, within a quarter of a mile of the col that connects this ridge with the mountain to the north, an exposure on the west side of the ridge at about 10,300 feet shows an unstratified deposit of clay, gravel, and bowlders in variety; on some of the bowlders faint striations were observable. On the east side of the ridge, glacial drift including well-striated bowlders occurs down to about 10,400 feet, joining here with the hummocky, irregular topography which has already been described.

The boundaries of the area just described are not clearly marked on all sides, but are approximately as mapped.

This area is classed as older drift because of (1) its topographic location, far above the clearly marked limit of the recent glaciation: (2) its composition, differing as it does from the more recent drift in the presence on the surface of many large, weathered bowlders,

including Potosi rhyolite, which is unknown in the more recent drift except in small fragments; and (3) the generally more weathered appearance of the surface, especially as compared with that of the more recent drift in the valley of Eder Creek below.

The ridge west of Eder Creek above the limit of the ice in the San Miguel valley, and up to about 10,000 feet, contains on the surface fragments of rock in variety including blocks of Potosi rhyolite up to 18 feet in diameter. At several places holes a foot or two in depth expose rounded, as well as angular, bowlders in variety. No cases of undoubted striation were observed. In the forest-covered portion, but few bowlders or rock fragments could be seen; on slopes free from trees numerous small fragments, including rhyolite, occur.

On the east, the area marked by rhyolite bowlders and fragments joins the deposits made by the glacier of the more recent epoch; on the west, it extends almost to the bottom of the next small valley, about a half-mile distant.

IN THE VALLEY OF REMINE CREEK

The valley of Remine Creek is irregularly fan shaped, with low, round-topped ridges radiating from the lower part of the valley above Keystone, until they are lost in the nearly even steep slope which stretches from timber line up to the very crest of Iron Mountain. Neither on the face of the mountain to the north, nor in the valleys below is there evidence of glaciation of the more recent epoch. Exposures of drift, with a few striated bowlders, are found at the two points indicated on the map, viz.: (1) on the eastern side at elevation 9,700 to 9,900 feet, and (2) on the western side at 9,400 to 9,700 feet. At both of these points, the exposure is due chiefly to the slipping of the surface layers on a steep slope of a hill 50 to 100 feet high; bowlders in variety up to 4 or 5 feet in diameter occur, mostly well rounded, but rarely distinctly striated. Large Potosi rhyolite bowlders do not occur here as in the areas near Eder Creek.

These two drift areas in the valley of Remine Creek are referred to the earlier epoch of glaciation because of their isolated position; that is, the absence of evidence of glaciation in other parts of the

valley, together with the generally mature stage of erosion of the whole basin.

ALONG DEEP CREEK

A little more than half a mile below the junction of the east and the west forks of Deep Creek, deposits occur estimated at not less than 30 to 40 feet in thickness at a maximum. As shown on the accompanying map, they lie chiefly on the east side of Deep Creek. In topography, the surface is in part irregular, but part shows some ridges approximately parallel to the tributaries of Deep Creek from the east. In composition, the deposit contains bowlders in variety up to 3 or 4 feet in diameter, many of them rounded; none with distinct glacial striations were found.

The deposits are classed as glacial on the evidence of the topography, the heterogeneous composition, the unstratified arrangement, and the rounded, subangular forms of the included bowlders. It is classed as older drift because of its disposition, discordant with the clearly marked deposits of the recent epoch farther up the stream, and because of the absence of evidence of recent glacial action in the upper part of the valleys of the tributaries next south of the east fork of Deep Creek.

ON THE WEST SIDE OF PROSPECT CREEK

At elevation 9,900 to 10,000 feet along the road parallel to Prospect Creek, glacial drift containing striated bowlders occurs at intervals for nearly a quarter of a mile. These exposures are on the southwest-facing slope of a round-topped ridge which separates the valley of Prospect Creek from that of one of its tributaries. The slope is here wooded, and the composition of the surface deposits is largely obscured.

NEAR THE JUNCTION OF THE TWO BRANCHES OF TURKEY CREEK

Deposits near the junction of the two branches of Turkey Creek occur as follows:

1. At a point about one-fourth of a mile above the junction of the two branches, glacial débris extends 20 to 30 feet up from the stream on the north side.

2. Just above the junction of the two branches a small accumulation of glacial débris lies between the two streams, joining the

ridge which extends to the southeast from this point. Just below the junction, on the north side of the stream, a distinct ridge begins, which is continuous to the edge of the glacial deposits made by the glacier moving down Lake Fork. The crest of this ridge is from 30 to 40 feet above the stream, and numerous sections show it to contain bowlders in variety such as occur to the east. The deposits made by the Lake Fork Glacier in the more recent epoch are characterized by an abundance of the light-colored granitic phase of the diorite-monzonite intrusions farther up the valley; but this diorite-monzonite is absent from the morainal ridge north of Turkey Creek just below the junction of the two branches. At the point where the stream crosses the eastern edge of the moraines of the Lake Fork Glacier, an exposure of drift on the south side of the stream about 75 feet in height shows diorite-monzonite bowlders in abundance and near the top of the exposure on the east side some stratified drift.

Above the deposit (1), named above, the course of the north branch of the stream lies in a narrow, steep-sided channel, in which are exposed enormous masses of Telluride and San Juan rocks tilted at angles up to 45° upstream; no recognizable drift occurs near the stream until the boundary of the moraines already described is reached, at elevation 10,100 feet. The valley of the south branch of Turkey Creek above the junction has a gradient less steep than the north branch, but in this direction also no drift is recognizable until at the mouth of the first small tributary from the east an alluvial fan shows bowlders evidently derived from the edge of the glaciated tract a half-mile to the east. A little farther up the stream, the western slope has a covering of bowlders in variety continuous with the deposit next to be described, which covers the southern end of the 10,100-foot hill lying west of the south branch of Turkey Creek at this point.

The deposits lying near the junction of the two branches of Turkey Creek are classed as older drift because of (1) their composition, which is different from that of the Lake Fork glacial deposits to which they are adjacent; (2) their position in a narrow valley which meets the edge of the Lake Fork Glacier in an angle acute in the direction of motion of the glacier; and (3) the unglaci-

ated channel of the stream for three-fourths of a mile above the highest of the deposits.

WEST OF THE SOUTH BRANCH OF TURKEY CREEK

On the southern end of the 10,100-foot hill west of the south branch of Turkey Creek, glacial débris extends from 10,100 feet elevation down to the stream on the east. The surface here consists of arkose soil with numerous bowlders, some rounded and some angular. On the south side at about 10,000 feet elevation a bowlder of Potosi rhyolite, 18 feet in diameter, has distinct glacial striae on a part of its surface where it has been measurably protected from weathering. Other Potosi rhyolite bowlders are found, one as much as 12 feet in diameter.

About one mile east of south from this hill on a southwestward-facing slope an exposure of drift occurs at elevation about 10,100 feet; the soil here also is arkose containing bowlders in variety, a few of which are striated. This area is continuous over the top of the ridge to the northeast, down to elevation about 10,000 feet.

These deposits are classed as older drift because of (1) their topographical position, 300 feet above the edge of drift of the more recent epoch; (2) their composition, including large bowlders of Potosi rhyolite which is unknown in the more recent drift except in small fragments; and (3) the weathered character of the material as shown by the arkose soil.

DIAMOND HILL, AND OTHER ADJACENT POINTS

Deposits classed as older drift are found on Diamond Hill (Fig. 15) and on other elevated points on the mesa between Big Bear Creek and Bilk Creek, as shown on the map (see Part I). The deposits in all these places so closely resemble each other in composition and general appearance that it would be impossible to distinguish one from the other if all were transferred to one place. The one most noticeable characteristic common to all is the presence of rather irregular bowlders of Potosi rhyolite from 4 to 10 feet in diameter, the larger size being the more frequent. Besides the Potosi rhyolite, other varieties of rock commonly present are basalt, diorite, diorite-monzonite, Telluride, quartzite, feldspar porphyry,

sandstone, and shale. Many of these bowlders, even of the hard varieties such as diorite, are well rounded. It is noteworthy that San Juan bowlders are absent. Striated bowlders were found in only one of the areas mapped, that is in the area lying east-west about three-quarters of a mile north of east from Diamond Hill. The deposit on Diamond Hill ranges up to 10 or 20 feet in thickness; the thickness at other points is not easily estimated, but may reach

FIG. 15.—Diamond Hill elevation 10,100 feet. Looking northeast from elevation 9,400 feet. Glacial drift of the earlier epoch covers the northern (left-hand) end of this mesa.

50 feet for the area three-quarters of a mile north of east of Diamond Hill.

These deposits are classed as older drift because of (1) their position, in disconnected patches on points ranging up to 500 feet higher than the nearest drift of the more recent epoch; and (2) their composition, including prominent bowlders of Potosi rhyolite which is not characteristic of the more recent drift.

ALONG THE STREAM SOUTHWEST FROM BLACK FACE MOUNTAIN

In the valley of the small stream heading at 10,600 feet elevation west of south of Black Face Mountain, glacial drift is exposed at intervals up to 10,700 feet. Clearly striated bowlders occur at 10,400 feet; at 10,500 feet bowlders in variety include Potosi rhyolite, the largest about 20 feet in diameter. Above 10,700 feet no glacial drift or other signs of glaciation are found.

This deposit is classed as earlier drift partly because of its composition, including large Potosi rhyolite bowlders, but chiefly because of the lack of evidence of glaciation in the upper part of the valley.

NORTH SIDE OF EAST DOLORES RIVER

North of the terminal portion of the glaciated tract in the valley of the East Dolores, rounded and subangular bowlders in variety occur at intervals up to elevation about 10,100 feet, that is, to a height of 400 feet above the upper limit of drift of the more recent epoch. The varieties most frequently found are diorite-monzonite and Telluride, with fragments of sandstone which is here the underlying formation. No good exposures or sections occur in this area, and no striated bowlders were found. The deposit is classed as drift because of its composition and its abundance. It is classed as older drift because of its topographic position and considerably weathered surface.

EAST SIDE OF EAST DOLORES RIVER

On the east side of the East Dolores River, above the mouth of the branch heading at Lizard Head Pass, a belt about three-eighths of a mile wide above the upper limit of glaciation as mapped for the more recent epoch contains occasional deposits of bowlders in variety, and an irregular topography including at the southern end of the belt some undrained depressions. The irregularity of the topography is, in part, clearly due to landsliding, but striated bowlders found in some parts of the area are evidence that the surface deposits include glacial material. As has already been stated, this belt is classed as older drift because of its topographic position, high up on the slope, and because of the relative scarcity of the drift in this belt as compared with the deposits of the more recent epoch near the stream.

NORTH SIDE OF STREAM HEADING WEST OF GRIZZLY PEAK

On the north side of the stream, outside the limit of glaciation of the more recent epoch, and extending down the valley to elevation about 10,600 feet, rounded and subangular bowlders are mingled, with shale fragments, including Telluride up to 8 feet in diameter, monzonite, and other forms of igneous rock. This area is classed as older drift chiefly because of the striking difference in topography, as compared with the newer drift above 10,700 feet elevation. At the limit of the more recent drift as mapped, the surface of the moraine near the stream is 150 feet above the bottom of the valley with a westward-facing slope of 30° to 35°. In the older drift area outside, the hillocks are low, with flattened crests and gentle slopes.

On the south side of the stream in the area of more recent drift, moraines also occur; on the south side of the stream opposite the older drift area, as mapped, are precipitous faces of outcropping rock or slopes of talus.

AREAS BETWEEN SHEEP MOUNTAIN AND EAST DOLORES RIVER

The area west of Sheep Mountain is for the most part heavily wooded, and the surface deposits are much obscured. At two places, however, glacial deposits were found. One area is at about 10,400 feet elevation, half a mile south of the limit of glaciation, as mapped, for the more recent epoch. It consists of a short ridge extending in a northeast-southwest direction, with some irregular topography including kettles on the west, and a nearly level area to the east joining the steeper slope above. An exposure on the western side of the ridge shows the usual composition for moraines. The other area includes deposits found near the stream which heads west of Sheep Mountain. From elevation about 10,400 feet up to 11,600 feet, drift occurs nearly continuously near the stream. For about a quarter of a mile above 10,500 feet elevation on the right side of the stream is a distinct ridge with top 30 to 40 feet above the bottom of the valley; this ridge consists of typical glacial débris, including striated bowlders. On the left side of the stream opposite this moraine, and on both sides up to 11,600 feet, the glacial deposit is often merely a surface covering, showing no distinctive topography characteristic of glacial deposits. Striated bowlders were found at 11,600 feet on the left side of the stream.

Below 10,400 feet occasional accumulations of gravel and bowlders in variety occur as far as the limit as mapped for ice of the more recent epoch. Much of this débris below 10,400 feet cannot be distinguished from valley train deposits, and is therefore not included in the area of older glaciation.

So far as composition and position are concerned, the deposits in these two areas west of Sheep Mountain might be referred to glaciation of the more recent epoch. They are classed as older drift because the valleys on the western side of Sheep Mountain from which it seems they must have been derived do not present the evidences of glaciation such as are found in the other high valleys which are known to have been occupied by glacial ice in the more recent epoch. It is possible that, with the fuller examination of this area which could be made if the forests were removed, relations of the drift of these areas may be established which will result in its reference to the more recent glacial epoch.

OTHER AREAS

At numerous other points, especially on the mesas between Remine Creek and Deep Creek, and again on points and ridges north of the East Dolores River, patches of bowlders occur which closely resemble glacial drift. But either because of poor exposure of the deposit, or because no striated bowlders could be found, these areas have not been mapped. Although not recorded because the evidence is considered insufficient to warrant their classification with undoubted glacial deposits, it is nevertheless believed that in many cases they represent remnants of former moraines, or possibly in some cases outwash plains from glacial sheets of an earlier epoch.

LANDSLIDES

Although not to be classed as glacial phenomena, a brief discussion of landslides and the topography resulting from them in the quadrangle is necessary because areas occur which present at the same time some of the characteristics of areas in which the materials have come to their present position by sliding or slumping, and some of the characteristics of typical morainal deposits. In most of the works previously cited reference is made to the frequent occurrence of landslides in the San Juan region, and in one, *Pro-*

fessional Paper 67, Mr. Howe has considered their occurrence and causes at length, and has called attention to the fact[1] that under certain circumstances masses of material moved by landsliding and masses deposited as glacial moraines may resemble each other so closely as to give rise easily to errors in interpretation. As criteria in such cases Mr. Howe says that "recourse must be had to strictly geologic evidence—that is, the condition and character of the material and its relation to rock in place."

In a discussion of the same problem as presented in the Uinta Mountains, Mr. Wallace W. Atwood[2] lays especial emphasis on the value of topography and topographic relations in the determination of doubtful cases of this kind, saying that "the chief criteria used have been, first, the topography of the material; second, the topography of the basin or valley affected; and third, the topographic relations in the basin or valley."

It is of course necessary constantly to bear in mind the fact that, so far as the region under consideration is concerned, the question usually most difficult to decide is not whether a given mass of material has its present form and position as a result (1) of glacial action exclusively, or (2) of landsliding exclusively; but that it is as a rule a very different one, embracing two distinct phases, viz.: (*a*) to determine with some degree of accuracy what share each of the two classes of agencies referred to above may have had in determining a given arrangement and location of débris; and after this is done, (*b*) to decide how completely the work of each class of agencies is to be represented on a map showing the geology of the region. Or, stated briefly and in order, the points to be ascertained about such doubtful areas are:

I. Agencies involved.
   1. Glacial action to the exclusion of landsliding.
   2. Landsliding to the exclusion of glacial action.
   3. Glacial action with later landsliding.
   4. Landsliding with later glacial action.
   5. Various successions and alternations of glacial action and landsliding.

[1] *Op. cit.*, pp. 16 and 17.

[2] *Professional Paper 61, U.S. Geological Survey*, pp. 63–65.

II. In the case of (3), (4), or (5), percentage of total action represented by each of the two agencies.

III. In the case of (3), (4), or (5), is the area to be mapped as landslide or moraine?

It is to be noted in regard to the points named above that as regards I, 1, it is highly probable that in strict literalness there is no morainal deposit anywhere which has not subsequently been subject in some degree to a settling and shifting of its materials, and if the deposits have had steep slopes some of these movements would no doubt deserve the name of landsliding; the same thing must necessarily be true of morainal deposits laid down on steep slopes of underlying material of whatever nature, or on any slope which is made up of materials which are themselves creeping, slumping, or sliding; but in many cases the amount of readjustment of material has evidently been so small that the effects due to landsliding may be disregarded. As to point III above, the question of representation on an areal map may sometimes be difficult to decide. It would seem that on a general areal map that agency should be represented which has clearly had the larger share in the transportation of the material at or near the surface; this necessarily means that agency which has most recently accomplished a notable amount of transportation of materials at or near the surface. On a map drawn to show especially glacial phenomena, even a small percentage of glacial débris may properly determine the inclusion of the area within the glaciated tract. Another method combining both of the above, used on the areal sheet of the *Engineer Mountain Folio*, is at times very desirable, especially in the case of valleys where the drift is in general small in amount, viz., to indicate the upper limit of glaciation by a definite line, and within the glaciated area to map moraines, landslides, bed rock, etc., as the character of the surface in the respective cases may warrant.

On the map (see Part I) the purpose has been to show clearly the maximum extent of glaciation in the recent epoch, and consequently no account has been taken of the fact that at some points within the areas indicated the débris has been notably readjusted in position by creeping, slumping, or sliding; this is especially true

(1) of the areas indicated as landslide near Trout Lake on the areal map of the *Telluride Folio*, and (2) the tongue of the landslide area extending to the westward down the east slope of the valley of Lake Fork, 4 to 5 miles south of Keystone. As noted in the detailed descriptions of glaciated valleys, there are numerous striated bowlders in the two regions referred to, but there has also been a marked amount of slipping and readjustment of material, so that the application of the principle laid down above, namely, that the most recent agency to produce notable results should take precedence, would require the mapping of landslide areas on an areal map practically as shown in the folio. The application of the same principle results, however, in some reduction of the area referred to as the Silver Mountain landslide by Mr. Howe.[1] For, as noted in the description of the upper part of the valley of Prospect Creek, and of the area west of Turkey basin and Alta basin, the topography and materials are in both cases characteristic of glacial action rather than of landsliding for some distance within the boundary of the landslide area as mapped in the folio. It is to be said, however, that the lower limit of the glaciated area as shown on the map (see Part I) is drawn somewhat arbitrarily, since the characteristics due to glacial action as already described, and those due to landsliding, are mingled together near the boundary in a manner which makes an accurate determination of the share which each had in the movement of materials difficult, or sometimes impossible.

With respect to the time relations involved in the landsliding, reference has already been made to observations which prove conclusively that some of the movements antedated the epoch of the more recent glaciation, as for example the great block of Potosi rhyolite two and one-half miles south of east of Trout Lake (Fig. 7). The well-cleaned-out cirquelike valley head to the northeast of this block, as well as the typical ground moraine topography of the glacial drift west of Turkey basin and Alta basin, shows that, at these points at least, the amount of landsliding since the recent glacial epoch has been insignificant, even though other areas near by in each case show evidences of a considerable amount of movement since the ice withdrew.

[1] *Op. cit.*, p. 17.

ROCK STREAMS

Within the Telluride quadrangle there are in all about 20 of the peculiar accumulations of angular rock fragments to which has been given the name of rock streams or rock glaciers; the location of the most of these is shown on the map (see Part I). The characteristics of such areas have been noted by various observers in this region, although none were recorded for this quadrangle at the time the folio was published. They occur for the most part at an altitude of 11,000 feet or more above sea-level, in cirques or in the upper portion of valleys at about the elevation at which cirques occur, usually at the base of precipitous walls of rock. They extend in some cases for as much as a quarter of a mile down the somewhat flattened bottom of the cirque, and rise as much as 20 to 30 or even 40 feet above the bottom of the narrow, valley-like depressions which separate them from the slopes of talus at the base of the side walls, as in the valley of the stream tributary to Mill Creek heading west of Dallas Peak. In other cases the rock stream consists of a belt or band of rock fragments lying approximately parallel to a steep cliff face, the distance covered being less in a direction perpendicular to the cliff than in the direction parallel to it, as in the valley of Canyon Creek east of Gilpin Peak, and in Middle basin, a tributary of the valley drained by Marshall Creek. In still other cases the rock stream covers an irregular area, but is located at about that part of the valley head where snow and ice collected in the winter would evidently be likely to be largest in amount, and protected in such a way as to be likely to remain longest in the spring, as for example the small area at the head of Turkey basin (Fig. 9).

In topography the surface of these areas resembles moraines in the following respects: (1) the elevations are usually in the form of ridges, sometimes irregular in arrangement, sometimes transverse to the direction in which the mass is being moved, and sometimes parallel or subparallel to the direction of movement; (2) between these ridges are many irregular depressions, corresponding to the kettles of typical morainic topography, having dimensions up to 100 by 25 feet and usually not more than 10 to 15 feet in depth, though one exceptional area in Middle basin has a depression 50 to

60 feet in depth. As to the outer boundary of these areas, the degree of slope is often as steep as can be formed by the fragments composing it. This is true both of the sides where the rock stream extends as a tongue down the valley, and of the lower end or terminal portion. In some cases, as in the area in Turkey basin (Figs. 10 and 11), the fragments making up the outer slope were found so insecure in their position as to make climbing difficult, numerous fragments sliding and falling down the slope whenever an attempt was made to secure a foothold.

In a few cases, as for example in Middle basin, a valley tributary to the valley drained by Marshall Creek, in the upper part of the valley of the tributary of Mill Creek heading west of Dallas Peak, in Savage basin, and in Ingram basin, rock streams of at least two distinctly different ages occur. The more recent is composed of fragments fresh in appearance, angular, and bare except for lichens on some of the surfaces. In the case of the older, the rock fragments are much disintegrated, so that the crests of the ridges are less sharp, and soil enough has accumulated to support vegetation, making the surface appearance that of rounded, green hills instead of bare ridges of angular fragments. These rock streams of earlier age usually lie at the lower or outer edge of the corresponding areas of more recent date, but in at least one case, in the upper part of Savage basin just beyond the eastern boundary of the quadrangle, the stream of unweathered fragments has passed around and beyond a small area of the earlier, appearing to have been deflected in its movement as by an obstacle, but spreading out again below the obstruction after having passed it.

To account for the presence of these accumulations of rock fragments two principal causes have been assigned, namely, (1) landslides, moving "with a sudden violent rush that ended as quickly as it started," and (2) the effect of the presence of interstitial ice, cementing the fragments together, and producing with changes of temperature a movement similar to that of glaciers. The former view is advanced by Howe in *Professional Paper 67, U.S. Geological Survey*, p. 54; the latter by Capps, in the *Journal of Geology*, XVIII (May-June, 1910), 362–64. Each of these authors recognizes other possible causes, but considers such others as may

be present as of minor importance. So far as the observations made by the author of this paper in the Telluride quadrangle give a basis for conclusions, it appears that these accumulations of rock fragments are due primarily to the work of ice as indicated by Capps in the article just referred to. The reason for assigning this cause as the principal one in the case of the rock streams in this quadrangle may be summed up from the descriptions already given as follows:

1. The topography of the surface, consisting of irregularly disposed ridges and kettle-like depressions.

2. The steep slope of the outer boundary, formed of fragments insecure in position, showing that they have been but recently moved to their present place.

3. The considerable distance which much of the material has been moved from the cliff from which it has been derived.

4. The location of these areas at elevations practically the same as that at which crevassed *névé* ice was reported "on the north slope of the high ridge east of Dallas Peak."[1] When this slope was visited in August, 1905, no mass of ice was visible, but rock streams were observed both on the north slope of this ridge and over the divide east of Gilpin Peak.

5. The location of a considerable number of the rock streams in positions where snow and ice would be most likely to accumulate in large amount, and likely also to be best protected from the sun's rays. The larger areas are, of course, found in positions directly exposed to the rays of the sun, but the smaller ones are far more abundant at the foot of northward-facing, or northwestward-facing precipitous slopes.

6. The relation in position of the rock streams of two distinctly different periods of movement in which the later appear to have moved around the earlier, deploying after passing the latter as in the case of actual glacial movement.

If the interpretation here given of the above phenomena is correct, the rock streams in this quadrangle are to be considered as representing incipient glacial movement. With respect to the last period of glaciation such movements are clearly to be regarded as

[1] *Telluride Folio*, p. 15.

part of the last, feeble, intermittent struggles of the glacial forces which earlier in the epoch acted with such vigor in the same region.

SUMMARY AND CONCLUSIONS

TOPOGRAPHIC EFFECTS OF GLACIATION

1. *Cirques.*—Almost all valleys in the quadrangle which have as much as half a mile of their course above 11,000 feet in elevation were occupied by glaciers in the more recent epoch; at the heads of many of these valleys cirques were developed. A typical cirque may be considered as having (1) a nearly perpendicular bounding wall, semicircular in plan, and (2) a comparatively level bottom. In a few places this typical plan is closely approximated; in most cases, however, there is variation in many ways. The bounding wall may be only a small arc of a circle, making the resulting cirque a broadly open one; or the nearly perpendicular faces of rock may be prolonged on each side of the valley for a mile or more in the downstream direction, producing a deeply recessed valley head which approximates the linear form characteristic of valleys. The slope of the bounding wall as a rule approaches perpendicularity only at some distance above its base—usually not more than the upper one-half of the vertical height of the wall shows the steep faces left by falling blocks or fragments (Fig. 9); at the base in almost all cases are slopes of waste, generally in the form of bare rock fragments, but occasionally so far weathered as to furnish a soil where an Alpine flora can gain sufficient foothold to cover the surface in the summer months with a carpet of green. The bottoms of the cirques also present variations. In some cases much of the floor is rock in place, frequently grooved and striated, and containing depressions in its surface in which are shallow lakes varying in size up to one-fourth of a mile or more in diameter. In other cases the floor is covered in whole or in great part with rock fragments and soil; the bottoms of such cirques are as a rule more irregular and less nearly horizontal than in the case of the cirques which contain lakes. Rock streams, already described, are found only in cirques or in the upper parts of valleys at a corresponding elevation.

2. *Hanging valleys.*—Numerous hanging valleys occur in the quadrangle; in most cases they were themselves occupied by

glaciers; in all cases the valleys to which they are tributary were glaciated. As to mode of formation, the hanging valleys in this quadrangle may be divided into two classes, viz.: (1) those due primarily to glacial deposition; (2) those due primarily to glacial erosion.

The valley of Prospect Creek is an example of class (1). The lower course of this stream was covered by glacial ice moving down the valley of the San Miguel River to which it is tributary, and the morainal deposits left by that glacier across the course of Prospect Creek have been eroded only in part by the stream, leaving the bottom of its valley just outside the moraine still about 350 feet above the level of the San Miguel River. Deertrail basin is an example of class (2). The bottom of this valley is about 1,500 feet above the level of the valley of the San Miguel River to which it is tributary. There is no means of determining just how much of the valley of the San Miguel was lowered by glacial erosion at this point, but from an examination of other tributaries near, it does not seem probable that it could have been more than a very small part of the 1,500 feet mentioned above. That the San Miguel valley was much less flat-bottomed in pre-glacial time than now hardly admits of question; the present steepness of the valley wall at the point where the stream from Deertrail basin enters must therefore be due primarily to lateral erosion by glacial ice. As has been pointed out by Russell,[1] this widening of a valley at the bottom is entirely sufficient to produce the phenomena of hanging valleys in the case of tributaries with a steep gradient. The very small size of Deertrail basin, however, together with the fact that the lower end of the basin is approximately at the same level as was the surface of the ice in the valley of the San Miguel River, indicates that the conditions of glacial erosion primarily responsible for making this basin a hanging valley are those stated by Russell for mountain-side glaciers,[2] viz., a gully or other depression occupied by a small glacier whose downward limit of erosion was a distance above the bottom of the main valley equal to the thickness of the ice in the main valley less the thickness of ice in the tributary.

[1] *Bulletin of the Geological Society of America*, XVI, 80.

[2] *Ibid.*

In this connection it should be noted that not all the valleys tributary to valleys which were occupied by glaciers are hanging valleys. For a given stream it may occur that part of the tributaries occupy hanging valleys, while a part are in topographic adjustment with the main stream. For example, east of the city of Telluride the San Miguel River receives tributaries from glaciated valleys as follows: Bear Creek, Deertrail Creek, Bridal Veil Creek, Ingram Creek, and Marshall Creek. Of these, Deertrail basin, Bridal Veil basin, and Ingram basin are hanging valleys, while Bear Creek valley and Marshall basin cannot be so classed. Of the two larger tributaries from the south, Bridal Veil Creek enters the cirquelike head of the San Miguel valley by a sheer fall of 350 feet and with a steep grade below for another 500 feet of fall before it reaches the more level part of the bottom of the valley; while Bear Creek, two miles farther west, draining a glaciated area less than that of Bridal Veil basin, enters the San Miguel River by a grade no steeper than is usual for mountain streams. Other things being equal, it would seem that a valley draining a small area would be deepened less by glacial action than one draining a larger area; and if so, then the smaller valley would be more likely to be left as a hanging valley. However, Bear Creek valley, the smaller one in this instance, is not a hanging valley, while Bridal Veil basin, the larger one, is; some modifying conditions have therefore evidently been present.

A modifying condition in this case may be (1) the difference in kind of rock forming the bottoms of the valleys. In Bridal Veil basin the San Juan formation is the underlying rock, while in the larger part of the valley of Bear Creek the more easily eroded sedimentary rocks of the Jura-Trias period outcrop in the bottom for two miles or more. Or the modifying condition may be conceived to be (2) a difference in the pre-glacial topography. If the grade of Bear Creek in pre-glacial time was not steep in its lower course, and if the downward cutting of the ice in the San Miguel valley was but little different in rate from that in Bear Creek valley, a hanging valley would not be formed. And on the other hand, a steep gradient in Bridal Veil Creek in pre-glacial time would, according to the principles already referred to in the case of Deertrail

basin, be sufficient to account for the lack of topographic adjustment as seen today. A complete explanation of the present difference between these two valleys must, without doubt, include both of the modifying conditions (1) and (2), just named.

In the case of Marshall Creek, only the second of these two modifying conditions can apply. This stream enters the San Miguel valley from the north at a somewhat steeper grade than does Bear Creek from the south, yet there is no abrupt change to a steep grade in its lower course such as is characteristic of streams in hanging valleys. Comparing again with Bridal Veil basin, the area drained by Marshall Creek is considerably less, so that so far as wear of channel due to ice alone is concerned it would seem that the valley of Marshall Creek would have been lowered by a less amount than was the valley of Bridal Veil Creek. The rock exposed in the bottoms of the two valleys is in this case the same, so that the only other modifying condition which appears to be sufficient to explain the difference seen today is that of the pre-glacial topography. That is, a gradient in pre-glacial time considerably less steep for Marshall Creek than in the case of Bridal Veil Creek or Ingram Creek is sufficient to cause the present difference. If this conclusion in the case of Marshall Creek be correct, it would seem probable that the modifying influence of pre-glacial topography predominated also in the case of Bear Creek, aided in a subordinate way by the presence of sedimentary instead of igneous rocks in the lower part of its course.

3. *Rounded topographic forms.*—Topographic forms rounded in outline due to glacial action, in contrast with the angular outlines usually found in unglaciated, mountainous areas, occur at many points in the quadrangle; they may be grouped as to origin in two classes, namely, (1) those due primarily to glacial erosion; and (2) those due primarily to glacial deposition. Class (1) includes (*a*) rounded, projecting points or masses of rock in place of which *roches moutonnées* are the type; and (*b*) valleys having a U-shaped cross-section as opposed to the sharper V-shaped section characteristic of unglaciated mountain valleys of steep grade. Class (2) consists of morainal deposits of various kinds, forming low, round-topped hills or ridges; sometimes these hills are in the bottoms of

valleys, as in the valley of the San Miguel River near Keystone (Fig. 4); sometimes they are on the tops of mesas 1,000 to 1,200 feet above the bottoms of the adjacent valleys, as on the mesa lying between Bilk Creek and Lake Fork.

4. *Silted-up lakes and ponds.*—Nearly level areas due to the silting-up of ponds or lakes occur at several points in glaciated valleys. The largest of these areas is in the valley of the San Miguel River (Fig. 3); it has a length of nearly five miles and a width of about half a mile. For the greater part of its course through this area the San Miguel River has a grade averaging about 30 feet per mile. In some parts of its course the grade is much less than this and the stream flows in wide meanders. At one point the generally level surface of this lacustrine plain is somewhat broken by low morainal hills; in other places it has been slightly modified by the accumulation of material in post-glacial time in the form of alluvial fans, a kind of modification to which practically all similar areas in the quadrangle are subject.

5. *Terraces and valley trains.*—Beyond the termini of the various glaciers, drift in the form of stratified deposits is usually found at intervals along the sides of the valleys, sometimes evident as narrow terraces or remnants of terraces. In the case of the San Miguel River these deposits extend beyond the boundary of the quadrangle, and are found at elevations up to 100 feet above the stream. The amount of débris left as valley trains is slight owing to the narrow, steep-sided valleys in which the streams flow.

CHARACTERISTICS OF THE DEPOSITS OF DRIFT OF THE EARLIER AND THE LATER EPOCHS

The drift deposits of the earlier and the later epochs are alike in being made up of a heterogeneous mixture of rounded and subangular rock fragments of various kinds and various sizes, including some bowlders and pebbles with striations.

The most important differences are with respect to (1) the kinds of rock present, (2) the topographic position of the deposits, and (3) the amount of erosion which has taken place since the withdrawal of the ice sheets to which the deposits of the two epochs, respectively, owe their origin. As to composition the drift of the

earlier epoch or epochs is characterized by bowlders of Potosi rhyolite up to 18 feet in diameter; that of the more recent epoch by bowlders of diorite-monzonite up to 4 feet in diameter, or of the San Juan formation up to 15 feet or more. Striated bowlders are, in general, rare in the earlier drift; in the more recent drift they are of common occurrence, and locally are abundant. As to topographic position, the deposits of earlier age occur in the majority of cases on the tops of mesas or ridges ranging up to 500 feet or more above the upper limit of the adjacent deposits of the more recent epoch. Some of the earlier drift, however, lies on slopes and in valleys in contact with the upper limit of drift of the more recent epoch just as if the earlier drift sheet had been in part overridden by the more recent glaciers. Not only does the older drift usually lie at a higher elevation than the more recent, but it also lies outside the drift boundary of the latter. In one case the earlier drift is found in a valley in which the more recent drift is not represented; in other cases the older drift lies at distances ranging up to one and one-half miles beyond the edge of the more recent deposits.

The difference in the amount of erosion to which the drift of the two epochs has been subject is shown both by the general field relations and by the topography of the deposits. The earlier drift deposits constitute in quantity a comparatively insignificant amount of material, distributed in isolated, small patches, at not less than twenty-five different places in the quadrangle. The more recent deposits, on the other hand, include prominent moraines and drift sheets which are in general continuous for each valley or drainage basin in which they occur. In topography, the earlier drift is characterized by a surface of greater regularity and smoothness, and by an absence of undrained depressions; the more recent drift, on the other hand, in a number of places shows a much more irregular surface with numerous kettle holes.

EXTENT OF GLACIATION

1. *In the more recent epoch.*—The number of glaciers occupying valleys in this quadrangle in the more recent epoch can be stated only in terms of number of terminal areas, and number of areas in which movement of ice originated. It must be remembered,

however, that this method of statement does not present complete information as to the number of glaciers which existed, for on each side of the quadrangle glaciers moved to undetermined termini beyond its borders; and on two sides glaciers moved into the quadrangle from points of origin outside. Within the quadrangle, however, there are between 80 and 90 points of origin, the exact number reckoned depending upon how many of the smaller tributaries of a given valley are considered as independent areas of initial movement. Of termini there are 14.

The total area glaciated in the more recent epoch is estimated at near 150 square miles. The greatest length of glacier lying wholly within the quadrangle, measured from terminus to most remote point of origin, is 15½ miles. Some of the glacial ice within this quadrangle, however, was tributary to the great Animas Glacier which is reported by Mr. George H. Stone[1] to have been 60 miles or more in length.

The maximum thickness of ice was probably something in excess of 1,500 feet. The slope of the surface of the ice varied from probably 1,000 feet per mile in the upper part of small valleys to 200 feet per mile or less in the lower part of the course of the larger glaciers.

The amount of glacial erosion cannot be estimated accurately from the deposits which are found, owing to the fact that much of the débris must have been carried away by the swift streams. But even when allowance is made for the disappearance of a considerable amount, it would seem that the whole amount removed by the ice was not in excess of 100 to 200 feet in average thickness for the glaciated tract; the maximum amount of erosion may, in places, have reached 400 to 500 feet.

As already stated in the description of the drift in the valley of the San Miguel River, the deposits near Keystone may be as much as 400 feet in thickness; this depth of drift is, however, very unusual for this quadrangle. Outside of the Keystone deposits the thickest are probably those found on the mesa between Bilk Creek and Lake Fork. The maximum height here of the top of the morainal hills or ridges above the bottom of the adjacent

[1] *Jour. Geol.*, I, 471 ff.

valleys is about 1,200 feet. This is not, however, a measure of the thickness of the glacial deposits, but is an indication of about the maximum thickness reached by the glacier at the point in question. The morainal deposits cannot exceed from 200 to 300 feet in thickness, and may be considerably less. The greater part of the total elevation of the top of the morainal hills above the bottom of the valley is due to the underlying rock in place which constitutes the walls of the canyon-like valley down which the glacier moved.

2. *In the earlier epoch or epochs.*—The occurrence of the older drift at and beyond the edge of the more recent drift is conclusive proof that the earlier glaciers covered a greater area than the more recent ones. With the exception of a few square miles in the northwestern part and possibly also in the southwestern part the entire area of the quadrangle must have been affected by glaciers in the earlier epoch. The appearance of the surface for a considerable length of time in that epoch must, therefore, have been that of snow and ice, except as it was broken here and there by projecting tops of peaks and ridges on whose steep slopes the snows could find no resting-place. In view of the great extent of the glaciers of the earlier epoch, and the large size of the bowlders which constitute a part of their deposits, glacial action in that period must have been sufficiently vigorous and long continued to produce important modifications in the topography. The details of such changes, however, can never be known; we can only be sure that the glaciers of that period played no small part in the general process of degradation which is still going on in the region. The isolated patches of earlier drift which are seen today are believed to be remnants of the moraines of that early period; those moraines must have retarded the erosion of the formations on which they were deposited, and so the elevation of the mesas and ridges on which these patches of drift occur must be somewhat greater than it would have been except for the protection thus afforded. Without doubt, therefore, some of the hills and ridges in the quadrangle owe part of their present elevation and some details of their configuration to the work of glaciers in the earlier epoch; but there are no means at hand by which to determine even approximately the amount of modification due to this cause.

AGE OF THE DRIFT

1. *More recent epoch.*—The age of the more recent deposits of drift is to be regarded as the same, in general, as that of the deposits of the Late Wisconsin stage of the continental ice sheet which covered the northern part of North America in Pleistocene time. It is evident, however, that the ice persisted in the upper parts of valleys until within very recent time, as shown by the crevassed *névé* ice reported a few years ago from the northern part of the quadrangle,[1] and by the signs of recent glacial movement seen in the rock streams, previously described in this paper. While correlated with the Wisconsin stage of the continental glacier, it is for the reasons just given to be understood that glacial ice remained in the quadrangle for a very considerable period after the continental ice sheet had disappeared from the northern part of the United States east of the Mississippi River.

2. *Earlier epoch or epochs.*—In considering the age of the earlier drift deposits it is to be observed that the drift referred to an earlier epoch or to earlier epochs of glaciation may be grouped as to position in two classes, viz.: (1) that found frequently on the tops of mesas or ridges, sometimes on slopes, at elevations ranging up to 500 feet above the upper limit of the nearest glacial deposits of the more recent epoch, and at distances ranging up to one and one-half miles beyond the edge of the more recent deposits; and (2) that found in valleys whose upper portions lack the usual evidences of recent glaciation.

It is to be understood that in grouping together certain deposits under the common name of earlier drift, no assertion is made as to the age of the respective deposits with reference to each other. From a consideration of the position of the two classes of deposits named above, however, the inference is clear that the amount of erosion since (1) was deposited has been very great, while the amount of erosion since (2) was deposited is comparatively small. It is, therefore, certain that all of the deposits classed as earlier drift are not of the same age. But the evidence afforded by deposits in the Telluride quadrangle is not sufficient to warrant the conclusion that three distinct glacial epochs are to be recognized. It

[1] Cross, *Telluride Folio*, p. 15.

may prove true that the deposits classed as (2) above should be regarded as merely early phases of the more recent epoch; but additional evidence from adjacent territory is needed before the matter can be placed beyond question.

The age of the oldest of the earlier drift as indicated by the amount of erosion which has taken place since the deposit was made is probably best shown on the mesa on which Diamond Hill is located. The vertical range of the earlier drift in this area is from 9,300 to 10,100 feet in elevation; the pre-glacial surface of the mesa must, therefore, have had a relief of about 800 feet; for the underlying rocks are here chiefly sandstones or igneous rocks, so that any considerable lowering of the surface due to solution as might have been the case in a limestone region cannot have occurred. Between areas of drift now at approximately the same elevation, valleys half a mile broad and 100 to 150 feet deep exist. The slopes of these valleys are gentle, the tops of the hills and ridges rounded or flattened, and undrained depressions are practically unknown. When it is remembered that most of the valleys separating the isolated patches of earlier drift are occupied by temporary streams only, and that for a considerable period the climate of the region has been semiarid, it is evident that the time represented by post-glacial erosion on this mesa is very long.

In considering the relation of the oldest of the earlier drift to that of the more recent epoch, one feature seemed especially prominent as the fieldwork was in progress; that is, the presence of large San Juan bowlders as the most conspicuous constituent of the more recent drift from the main valley of the San Miguel, and similarly, equally large Potosi rhyolite bowlders, characteristic of the oldest of the earlier drift on the mesas and ridges adjacent to the same stream. The presence of large bowlders of a given formation in abundance in drift of a certain period at once raises questions as to the conditions under which glaciers get possession of an abundance of large rock fragments. Judging from the composition of the drift brought down the main valley of the San Miguel to Keystone, and from the relation of the exposures of the various formations in the upper valleys tributary to the San Miguel, it would seem that an abundance of large bowlders in drift is to be

considered as an indication of "plucking" in the bottom of glaciated valleys. It is conceivable that the process of sapping might result in large blocks of rock outcropping above the surface of the ice to fall and be carried on the surface; and there can be no doubt that this sometimes occurs. But in the case of the cirques tributary to the San Miguel River, the summit of their bounding walls consists of an almost continuous ridge of Potosi rhyolite ranging up to about 1,000 feet in vertical extent, 500 feet or more of which was probably all the time above the surface of the glaciers filling the cirques. Yet in the drift left by the ice from these valleys, the Potosi rhyolite is indistinguishable except in small fragments. On the other hand, the San Juan formation, which occurs in the drift in abundance in bowlders up to 18 feet in diameter, outcrops in the lower part of the cirque valleys from 10,000 to 12,000 feet in elevation, and presents in many places the precipitous walls in the bottoms of the valleys transverse to the streams which have been referred to as giving to these valleys a roughened, unglaciated appearance when viewed from below. The appearance of the faces of these cliffs transverse to the valleys is such as would result if the rock were plucked off in large masses. If sapping had any considerable share in supplying the large bowlders of the San Juan formation found near Keystone, it must have occurred at the points where valleys such as Bridal Veil Creek and Marshall Creek join the San Miguel. Here the San Juan formation was exposed in precipitous walls 1,500 to 2,000 feet above the surface reached by the ice. There is no evidence, however, that lateral erosion at these points was sufficient to amount to undercutting; the walls are precipitous but not roughened as if by the removal of large blocks, and the débris which is now falling is for the most part small fragments.

The other drift deposits of the more recent epoch are not characterized by large bowlders. Drift brought by the Lake Fork Glacier is characterized by diorite-monzonite bowlders rarely over 3 or 4 feet in diameter. This formation outcrops in the bottom and sides of the valley in the neighborhood of Ophir Station where precipitous plucked faces occur. Here also the upper slopes of the sides of the valley above the elevation reached by the surface of the

ice may be considered as possible sources of fragments; but they present no evidence of undercutting or of sapping.

It will require much more extended observation to determine without question what the precise relation may be between the average elevation of an area of glaciation and the horizon of a formation prominently represented in the drift by large fragments. But the evidence, as far as observations in the valleys of this quadrangle are concerned, points to the conclusion that an abundance of large bowlders of a certain formation in the drift from a given glaciated area indicates an outcrop of the formation in the bottom and sides of the middle and lower parts of the high valleys in which the glaciers in question were formed. As the San Juan formation lies at approximately 10,500 to 12,000 feet in elevation for its lower and upper limits, respectively, and as the Potosi rhyolite has its lower limit at about 12,500 feet elevation, we should have, on the basis of the foregoing conclusion, a position of the middle part of high glaciated valleys in the earlier drift epoch of not less than 1,000 feet above the level of the present cirque valleys. Or, in other words, that sufficient time has elapsed since the period of the earlier glaciation in this region to permit the removal by erosion in the high mountain tracts of not less than 1,000 feet of igneous rock. This interval of time manifestly must include (1) an interglacial interval, which presumably was of long duration, and (2) the period of more recent glaciation.

POST-GLACIAL CHANGES

The changes due to agencies acting in post-glacial time are chiefly the formation of alluvial cones and fans, alluvial and lacustrine deposits along streams and in lakes or ponds, and talus slopes, and in the renewal of the process of downward cutting by streams in nearly all the valleys. Of the deposits named, the accumulations of talus are largest in amount, slopes of talus 1,000 feet or more in length occurring in a few places. But the total amount of all the post-glacial deposits is insignificant; they are, in general, recognizable only at the base of cliffs or steep slopes and at certain places in the bottoms of valleys. The amount of post-glacial erosion is also in all cases relatively very small; the materials of the drift

generally present a fresh, unweathered appearance; undrained depressions in morainal tracts are still numerous; and streams have cut channels in bed rock not more than 10 to 20 feet in depth in the more favorable locations.

GLACIATION AS AFFECTING THE LOCATION OF MINING CLAIMS

It is reported that the first prospectors in this region found some exceptionally large fragments of ore-bearing rock on the lower slopes of valleys now known to have been glaciated; small fragments are still occasionally met with. In a few cases it seems that these fragments have been taken to be an indication of an outcrop of a vein near by, and considerable effort has been expended in driving tunnels into the underlying bed rock in search of the ore body from which the fragments came. It should be remembered, however, that if fragments of ore-bearing rock are found on the surface within the area shown to have been glaciated, they have little value as indicating that the parent vein or ledge is near at hand. This is particularly true of those parts of valleys in which moraines are found; fragments found in the upper parts of valleys which are comparatively free from débris are more likely to be but a short distance from the outcrop of the body of ore. But the general rule is nevertheless in all cases to be recognized, that fragments found on the surface in any part of a glaciated area may have been derived from a ledge close at hand, or may have been brought from any point in any part of the valley above.

ON THE STRATIGRAPHIC POSITION AND AGE OF THE JUDITH RIVER FORMATION

A. C. PEALE

PART III

THE PALEOBOTANICAL EVIDENCE

We have as yet no fully diagnostic flora for the Judith River beds, the plants from them being few in number and confined to two localities, one of which is in reality not positively placed stratigraphically. This meager collection, therefore, is by itself inconclusive. That fossil plants will be found later on is undoubtedly true, as indications of their presence have been noted, but they are evidently not abundant in the formation, careful search on our flying trip having proved entirely unsuccessful. In this connection it may be said that plant remains are similarly infrequent also in the Lance formation and in the Edmonton or "Lower Laramie" of the Canadians. The plants described from Willow Creek by Knowlton[1] from the beds referred to the Judith River by Stanton and Hatcher[2] are undoubtedly of Belly River age and do *not* come from the Judith River formation.

In 1908 fossil plants were collected by members of the U.S. Geological Survey from beds supposed by them to be of Judith River age near the Macklin Coal Company's mine on the Big Sandy in Montana. This locality is about 12 miles northeast of the Big Bend of the Missouri River below Fort Benton, and between 30 and 35 miles northwest of Judith Landing on the Missouri River near the east end of the Bearpaw Mountains. The list of plants as identified by Dr. Knowlton is as follows:

Viburnum perplexum Ward.
Plantanus nobilis Newberry.
Populus sp. (large leaf).

[1] *Bull. U.S. Geol. Surv., No. 257*, pp. 129–55.

[2] *Ibid.*, pp. 56–58.

Populus cuneata Newberry.
Populus glandulifera Heer.
Berchemia multinervis Al. Br.
Viburnum sp.
Sapindus grandifolius Ward.
Taxodium distichum miocenum Heer.

These are of undoubted Fort Union age, but as the named species are common to both the Upper and Lower Fort Union (Lance) formations, it is impossible, without knowing the exact stratigraphic relations, to say which of the two they represent. The probabilities are that they are from the Lower and are, therefore, from the Lance, that is, that they are really from the Judith River (not Belly River) beds, in accordance with the belief of the collectors; and they are likely to have come from the upper part of this series. However, at the present time it is impossible to make any very positive statement regarding them.

The second locality is on Cow Creek, where Dr. Stanton found many leaves of *Trapa(?) microphylla* about 30 feet above the base of the Judith River beds. This species has a wide distribution in the Fort Union formation, occurring in both the Upper and the Lower Fort Union beds, having been found abundantly by Professor L. F. Ward at Burns ranch on the Yellowstone below Glendive and at many other localities and by other collectors in the Lance formation in Converse County, Wyo. It is also found in the Canadian "Lower Laramie" which, as we regard it, is the equivalent of the Lance formation and of the Judith River beds. The type of *Trapa(?) microphylla* was described by Lesquerreux from the Montana formation of Point of Rocks, but, as Knowlton[1] has indicated, it is questionable whether the species from the Montana and from the Fort Union and underlying beds are all one and the same.

In regard to the plants of the Lower Laramie (or Judith River series in Canada), concerning which Dawson[2] made the statement that "the flora of the Belly River closely resembles that of the Lower Laramie," it is to be urged that comparison of the two lists shows that the resemblance between the floras is, after all, not very

[1] *Bull. U.S. Geol. Surv., No. 163*, 1900, p. 63; *ibid., No. 257*, 1905, p. 145.

[2] *Trans. Roy. Soc. Canada*, III, sec. IV (1885), p. 20.

striking. Besides, as Dawson[1] himself adds, "the few species are scarcely sufficient to afford a basis for definite conclusions." The list for the lower division of Dawson's Laramie contains eight species, of which six are common to both Upper and Lower. Two of the species, *Onoclea sensibilis* and *Sapindus affinis*, are characteristic of the Fort Union in both of its divisions on the American side of the line. As to the Belly River list, it does not seem to be complete, *Pistia corrugata*, a characteristic Montana flora not being included. Adding this to the list, we have ten species, two of which, according to Knowlton, should be dropped. Only two of those remaining seem to be common to both Belly River and Lower Laramie, and this small proportion certainly cannot be said to establish a striking resemblance between the two floras. Regarding the others, Knowlton says:[2]

> As to the affinities of the other named species, it may be mentioned that *Nelumbo dawsoni* is very closely allied to my *N. intermedia* from Point of Rocks, Wyo., while the other two species (*Populus latidentata* and *Acer saskatchewanse*) are not figured, nor are they described with sufficient fullness to permit of satisfactory comparison with other forms.

Stanton[3] was probably correct when he said:

> I suspect that in Canada two distinct formations, separated by marine beds, have been confused under the term Belly River series, and that a large part of the fauna, and possibly also of the flora, was collected from the upper horizon, which included the Laramie and possibly even later beds.

It seems equally true that in this country the same formations have been confused. Our knowledge of the flora, of the Lance formation, has been considerably enlarged in the past few years.[4] The Belly River flora, however, is in need of critical study, and until that can be done we must content ourselves with the confident prediction that the difference between them will be greater than now appears; and that when a flora for the Judith River beds is developed, its affinities will be with the Lance rather than with the Belly River flora indicated above.

[1] *Trans. Roy. Soc. Canada*, IV, sec. IV (1883), pp. 32, 33.

[2] *Bull. U.S. Geol. Surv., No. 257*, 1905, p. 154; see also *ibid., No. 163*, 1900, pp. 9, 10.

[3] *Ibid., No. 163*, 1900, p. 11.

[4] See Knowlton *Proc. Wash. Acad. Sci.*, XI (1909), 179–238.

THE INVERTEBRATE EVIDENCE

According to Dr. T. W. Stanton:[1] "As the Judith River is essentially a non-marine formation, strictly speaking its fauna should not be made to include the marine species" which in the one occurrence noted by him, he supposes to have been "brought into the Judith River area by a local temporary invasion of pure marine waters." There is also in the formation "a brackish-water fauna of wide geographic distribution confined to thin beds in its upper and lower portions of the formation."

It is apparently the consensus of opinion among invertebrate paleontologists that fresh-water faunas *per se* are of little or no value in the accurate determination of the age of beds in which they occur. Fresh-water beds are found at a number of horizons between the Devonian and the present time. In the Devonian, shells resembling the modern Unio have been found and Unios of similar types have also been collected from the Triassic and Jurassic. Writing of the fresh-water beds at the top of the Jurassic Dr. Stanton[2] says:

> Its invertebrate fauna consists of several species of *Unio, Vivipara, Planorbis*, etc., all of modern fresh-water types, which do not assist in discriminating between Jurassic and Cretaceous. Unios have been found in several horizons in the Cretaceous, and when we get as high as the Ceratops beds (Lance formation) many, if not all of the specific types found there, may be found also among living species.

Whitfield[3] describing the Unios from the Hell Creek region of Montana says of fourteen species that they are "so nearly like the living species that it would do but little violence to specific features to say they were the same."

Writing of the non-marine faunas found in the Ceratops beds of Converse County, Wyo., Stanton says:[4]

> It must be admitted that in themselves, without any reference to stratigraphic occurrence or local geologic history, these fossils could not be depended

[1] *Bull. U.S. Geol. Surv., No. 257*, pp. 119 f.

[2] *Jour. Geol.*, XVII (1909), 414.

[3] *Bull. Amer. Mus. Nat. Hist.*, XXIII (1907), 624.

[4] "The Age and Stratigraphic Relations of the 'Ceratops Beds' of Wyoming and Montana," *Proc. Wash. Acad. Sci.*, XI (1909), 288.

upon for the discrimination of horizons within the Cretaceous nor for distinguishing between Cretaceous and Tertiary.

Fresh-water invertebrates therefore cannot be depended upon as time-markers in geologic investigations; still it is true as Stanton further says:[1]

> When the investigation is confined to a single region and when the geographic and stratigraphic range of non-marine species has been determined their evidence is useful and important.

Therefore, from the viewpoint of the present writer the stratigraphic position of the Judith River beds is the same as that of the Lance formation, or the lower portion of it; a comparison of their fresh-water faunas is interesting and instructive, because it corroborates to a considerable extent the more conclusive evidence presented by the vertebrates.[2]

THE VERTEBRATE EVIDENCE

Hayden in his early explorations in 1855 collected in the Judith River basin, not only marine invertebrates from the Fox Hills sandstones underlying the fresh-water fossiliferous Judith River beds, but also obtained from the latter, vertebrate remains which constitute the first horned dinosaurs of the *Ceratopsia* ever collected in this country. These, and other specimens from near Long Lake, N. D., in what is now called the Lance formation, were studied by Dr. Joseph Leidy, resulting in the establishment by him of four genera and species of dinosaurs.[3] Later, his descriptions were elaborated and published[4] with illustrations. Although in his first article, Leidy thought that the Judith River formation might be of Wealden age, in his second publication he was inclined to consider the formation as "a part of the great Cretaceous series of Nebraska, though [he says] we should not feel surprised if future explorations should determine it to be of Tertiary age."[5] In the

[1] *Proc. Wash. Acad. Sci.*, XI (1909), 285.

[2] Stanton, *op. cit.*, p. 286, refers to the widespread association of some of the species in association with the dinosaur fauna, stating that a "large proportion of them, including some of the more striking and characteristic forms, occur at Black Buttes."

[3] *Proc. Acad. Nat. Sci., Phila.*, VIII (1856), 72–73.

[4] *Trans. Amer. Phil. Soc.*, XI, N.S., Philadelphia, 1860, pp. 138–54.

[5] *Ibid.*, p. 140.

opinion of the writer this prophecy of Leidy's made in 1860 is today being verified.

Professor E. D. Cope, with the assistance of C. H. Sternberg and John C. Isaacs, spent a part of the summer of 1876 in the exploration of the Judith River basin between Fort Benton and Armell's Creek, 130 to 150 miles farther down the Missouri River,[1] and secured a considerable number of dinosaurs, referable to several new genera and species, and fragmentary remains afterward determined to be *Ceratopsia*. Hatcher spent a couple of months of the summer of 1888 in the Judith River badlands with what he calls very indifferent success,[2] and in the summer of 1903, with T. W. Stanton, spent two more months "in the field study of the Judith River and associated formations of northern and central Montana and adjacent areas of Canada."[3]

In the interval between 1855 and the present time (1912) explorations have been carried on over widely separated areas in the Rocky Mountain region of the United States, resulting in the discovery and development of many localities from which vertebrate remains (many in a fragmentary condition) have been collected, the beds in which they occurred being post-Laramie formations. The most characteristic species appear to be those of genera belonging to the *Ceratopsia*, one of the first described species coming from the beds at Black Buttes, Wyo.

Besides the localities in Converse County, Wyo., collected by Hatcher, Williston, Baur, and Case, and the Denver and Arapahoe areas of Colorado by Cannon, Cross, and Eldridge, and the Hell Creek region by Barnum Brown, many others in the Rocky Mountain region have yielded vertebrate remains, mostly, however, in a fragmentary condition. Thus *Ceratopsia* have been found near the North Platte River in Wyoming about 40 miles north of Fort Steele by Hatcher in 1888, and from near the same locality by Knowlton and Peale in 1910, here also by Hatcher, on the east side of the Big Horn Mountains 40 miles south of Buffalo, Wyo.; on the west side of the Big Horn River between Fort Custer and Custer Sta-

[1] *Bull. U.S. Geol. and Geog. Surv. Terr.*, III (1877), 565–97.

[2] *Monograph U.S. Geol. Surv.*, XLIX (1907), 7.

[3] *Bull. U.S. Geol. Surv., No. 257*, 1905, p. 9.

tion, Mont.; and north of Musselshell, Mont. In addition to the Hell Creek specimens listed by Barnum Brown he collected *Triceratops* and *trachodont dinosaurs* south and southeast of the Yellowstone River in Montana, Wyoming, and the Dakotas. Throughout this general area also the various parties of the U.S. Geological Survey engaged in tracing the distribution of the coal formations during the past six years have brought in numerous vertebrate specimens of similar character, showing their wide distribution in the Lance formation.

As noted on a preceding page, Hayden was unable to detect any material difference between the deposits of the Judith basin and those of the Fort Union, especially of the portion lying at the base of the latter in the Missouri River region extending to the eastward. Similarly all the earlier paleontological workers could not make any separation based on the vertebrate remains found in them and did not separate the Judith River beds faunally from the beds, that, at Long Lake, N.D., and along the Yellowstone River and several other localities, lie immediately below the undisputed Fort Union. Cope also in his work in northeastern Colorado recognized that he was dealing there with beds identical with those of the upper Missouri River country, especially the reptile-bearing portion of the Fort Union.[1] As the area of exploration in the west widened, and collections, fragmentary as most of them were, increased, and admittedly insufficient and fragmentary as is the material from the Judith River basin, the more evident became the remarkable resemblance between the faunas from the beds now referred to the Lance formation and those of the Judith River beds. Undoubtedly this would have been still more evident had there not been a strong effort to differentiate them, due to a misapprehension as to the supposedly vastly older age of the Judith beds as deduced from supposed stratigraphic evidence. The probability of the Judith River beds being of post-Laramie age on account of the stratigraphic position and the contained vertebrate remains is referred to by Cross.[2]

[1] *U.S. Geol. and Geog. Surv. of Terr. for 1873, 1874*, pp. 429, 430.

[2] *Monograph U.S. Geol. Surv.*, XXVII, 239.

Williston[1] notes a "startling resemblance" between the Wyoming Laramie [Lance Creek] fauna and that of the Judith River and Belly River series. Of course, if they are equivalent to each other, as we claim, this resemblance is not so startling. Williston, however, is not alone in mentioning this resemblance. Hatcher[2] himself says:

> When considered in its entirety, the vertebrate fauna of these beds [Judith River beds] is remarkably similar to, although distinctly more primitive than, that of the Laramie [Lance formation]. Almost or quite all of the Laramie [Lance formation] types of vertebrates are present, though as a rule they are represented by smaller and more primitive forms.

However, it remained for Dr. O. P. Hay[3] fully to bring out this resemblance and demonstrate the equivalence of the Judith River and Lance formations. Having demonstrated, as he supposes, that there was a nearly complete change in the fauna and a considerable change in the flora between the time of the deposition of the Lance Creek beds and those known as Puerco and Fort Union, he says:

> I will endeavor to show that the fauna of the former beds is closely related to that of the Judith River. This close relationship of the two faunas has been recognized, it may be truthfully said, by all paleontologists who have given attention to the subject.

In his discussion of the relationship of the two faunas Dr. Hay begins with the fishes and follows with the tailed amphibians. He quotes Hatcher, who says eight species of fishes have been described from the Judith River deposits. Of these Hatcher says:

> While they give an indication of the character of some of the fishes that inhabited the waters of this region in Judith River times, they are at present known from such insufficient material as to render them of little value for purposes of correlation, as is abundantly evidenced by the apparent similarity existing between the fish remains known from these beds and those from the Laramie [Lance formation]. This similarity is so striking that some paleontologists have been led largely from such evidence to *correlate the Judith River*

[1] *Science*, N.S., XVI (1902), 952.

[2] *Bull. U.S. Geol. Surv., No. 257*, 1905, p. 107.

[3] Reprint from the *Proc. Ind. Acad. Sci.*, Twenty-fifth Anniversary Meeting, 1909, pp. 1–27.

beds with the Laramie [Lance], *disregarding the more important evidence afforded by the dinosaurian fauna and the stratigraphy.*[1]

The italics above are the writer's. Here again we run up against the stratigraphic misapprehension already alluded to. As to the dinosaurian evidence, as we shall presently see, its trend is the same as that afforded by the fishes. It is axiomatic that only the species common to any two or more formations are of any use in correlating them. *Lepidotus occidentalis* Leidy, described in 1856 from the Judith River beds, has been found by Williston[2] in the Lance formation of Converse County, Wyo., and by Barnum Brown in the Lance formation in the Hell Creek region. With this *Lepidotus* Williston found also another species, *Myledaphus bipartitus*, named by Cope from the Judith River beds. This seems to be a ray according to Hay,[3] who says: "The rays are almost wholly inhabitants of salt water; hence the persistence of this Judith River fresh-water form is somewhat remarkable." Another species of *Diphyodus*, a genus founded on a jaw fragment from a Canadian locality, is said by Hatcher to be common both in the Judith River beds of Montana and in the Laramie [Lance] deposits of Converse County, Wyo., and a species of the same genus was found by Barnum Brown in the Hell Creek beds. The tailed amphibians, which Hay says are at all times rare fossils, are all referable to the genus *Scapherpeton*, and five species were described by Cope from fragmentary material obtained in the Judith basin of Montana. Williston found one species in the Lance formation and Brown reported a species from the Hell Creek beds. Hatcher considers the batrachia of the Judith River beds of no special importance in determining the age of the deposits or in correlating them with other formations. Dr. Hay, however, referring to them says:[4]

While it is true that these fishes and amphibians are mostly represented by fragmentary remains, these remains are usually characteristic and capable of accurate comparison. That *Myledaphus* should reappear after an interval allowing the deposition of 1,000 feet of marine strata, and probably some hundreds of feet of fresh-water strata, is remarkable enough; but that it should reappear in company with its old companions, the rare *Diphyodus and Scapher-*

[1] *Bull. U.S. Geol. Surv., No. 257*, p. 67.

[2] *Bull. Amer. Mus. Nat. Hist.*, XXIII (1907), 842.

[3] Hay, *op. cit.*, p. 20.

[4] Hay, *op. cit.*, pp. 20, 21.

peton, not to mention the more highly developed fauna yet to be discussed, is very striking. Had there occurred at both levels only some pebbles of three peculiar forms or compositions, instead of the three genera, the conclusion would have been inevitable that there was some particular connection between the two formations.

When we realize that there is no interval between the Judith River beds and the Lance formation, allowing the deposition of thousands of feet of marine strata, we see that there is no remarkable reappearance of *Myledaphus* and its companions, but that they have simply coexisted in beds of the same age at different localities. As to *Champsosaurus* and the Crocodilia, it will serve our purpose here just to quote Dr. Hay, who says:

> Coming next to the reptiles, it may first be noted that species of *Champsosaurus* occur in the Judith River beds, in the Lance Creek beds, in those of the Hell Creek region, and in the Puerco. It is probable that the species vary from one formation to the other. The same statement can probably be made regarding the crocodiles. *These genera, common to all three of the formations under discussion, may be left out of consideration; although it must not be overlooked that, none the less, they aid in binding together the formations in which they are found.* As to the crocodiles, it may be mentioned that Williston recognized, in teeth and scutes found in the Lance Creek beds, Leidy's *Crocodylus humilis*, originally described from the Judith River region. From the Judith River beds of Alberta, Lambe described *Leidyosuchus canadensis*. Mr. C. W. Gilmore will soon describe a second species of the genus, collected last summer in the Lance Creek beds of Converse County, Wyo.

The sentence italicized by the writer in the above quotation is the one specially pertinent to the present discussion.

As regards the turtles which have been especially studied by Dr. Hay, he says:

> My study of the fossil turtles indicates that the species of these animals rarely pass from one epoch to another. If they have ever done so, they passed from the Judith River into the Lance Creek epoch. There are five or six species of Judith River turtles which are represented in the Lance Creek and Hell Creek beds by turtles of identical or very closely related species. Most of these are marked by such peculiar sculpture that they are easily recognized and some of them likewise are represented by excellent materials.

Dr. F. H. Knowlton has recently shown conclusively[1] that, of the sixteen species of turtles accredited by Hatcher to the Judith

[1] Knowlton, *Proc. Wash. Acad. Sci.*, XII (1911), 51–65.

River beds, only nine are actually found in the Judith basin of Montana. Four of these are types and of these, only two are confined to the Judith beds. The other seven are common to both the Judith and Lance formations which, in view of what Dr. Hay has written, is good proof of their identity in age.

The most abundant and conspicuous reptiles in both the Judith River and the Lance formations are the dinosaurs, and practically half of those listed by Hatcher are common to both formations. Writing of these dinosaurs Dr. Hay says:[1]

> Five families of these, belonging to four super-families and to two suborders, are represented in the Judith River epoch, and each of these families reappears in the Lance Creek epoch. Furthermore, many of the genera are common to the two formations and it is believed that the same is true of a considerable number of species.

Hatcher in his summary in the consideration of the dinosaurs[2] says that "they of all the vertebrates of these beds [Judith River] afford the best basis for a comparison of the fauna of these deposits with that of the Laramie [Lance] above (?) and the Jurassic below." He says the great group of Sauropoda which formed a conspicuous feature at the close of the Jurassic and the beginning of the Cretaceous is entirely wanting, and that the Stegosauria, which formed a striking feature among the Jurassic dinosaurs, have almost or quite disappeared, being entirely replaced by the quadrupedal Ceratopsidae and the bipedal Trachidontidae. "No unmistakable representative of the Stegosauria is certainly known from the Judith River beds. *Palaeoscincus*, referred to this suborder chiefly on the evidence of teeth alone, may or may not pertain to the Stegosauria, while *Stereocephalus* appears to have been founded on material belonging in part to the Crocodilia and in part to the Dinosauria." On the following page Hatcher states that these Dinosauria are not distinguishable from remains from the Laramie [Lance] at present referred to the Ceratopsia. Whether or not *Palaeoscincus costatus*, described from the Judith River badlands by Leidy in 1856, is represented in the Lance formation by numerous teeth[3] cannot be positively stated. The genus is represented

[1] *Op. cit.*, p. 23.

[2] *Bull. U.S. Geol. Surv., No. 257*, pp. 101–3.

[3] Hatcher, *op. cit.*, pp. 83, 88; Hay, *op. cit.*, p. 23.

in the Hell Creek region and in Converse County, Wyo. Hatcher[1] says:

> The Trachodontidae had already attained to considerable diversity in Judith River times. Indeed they appear to have been more abundant as regards both numbers of individuals and genera and species than they were in the Laramie [Lance]. Judging from the rather meager material at hand for comparison, they were, however, somewhat less specialized.

As to the Theropods, he says that so little is at present actually known from either the Laramie [Lance] or the Judith River beds "that it is quite impossible to make anything like an adequate comparison between them. The group, however, is represented in both formations by quite similar forms, though differing perhaps both generically and specifically." This statement appears to be little more than an assumption, inasmuch as about half the identified species are common to both formations. Although as Hay says,[2] much has yet to be learned of the Ceratopsia, especially of the Judith River forms, the knowledge of which is still somewhat vague, most of the remains from that region being of incomplete skulls. However, the interest in them has been so great that they have been studied with extraordinary care. This fact doubtless influenced Hatcher's statement: "It is in the Ceratopsidae more than in any other group that we are at present able to contrast the Judith River and Laramie [Lance] forms."[3] Hatcher's conclusion based on this comparison is as follows:

> The primitive nature of the Judith River Ceratopsidae as compared with the Laramie [Lance] is especially seen in the *smaller size of the individuals, the less perfectly developed armature of the skull, and the imperfectly developed parietal crest.*

The italics are Hatcher's.[4] This supposed contrast in the forms from the two formations is reiterated by Hatcher throughout his paper and in his monograph on the Ceratopsia edited by R. S. Lull and published by the Geological Survey.[5] Osborn, in making the same contrast, comparing especially the nasal and supraorbital horns mainly of the species of *Monoclonius* and *Ceratops* (found in

[1] Hatcher, *op. cit.*, p. 102.

[2] Hay, *op. cit.*, p. 24.

[3] Hatcher, *op. cit.*, p. 102.

[4] *Ibid.*, pp. 102, 103.

[5] *Monograph U.S. Geol. Surv.*, XLIX (1907).

the Judith River beds) which he says are very similar if not generically identical, says:[1]

> It will be observed that five of these species [of *Monoclonius* and *Ceratops*] are known to possess large nasal and small supraorbital horns. This stage of horn evolution *may* be contemporaneous and independent of that on the southern Laramie [Lance] dinosaurs in which the nasal horns are invariably smaller than the frontal horns, but coupled with the smaller size and open temporal *fossæ* it would appear to be more primitive.

The italics above are Osborn's and they seem to be justified by the fact that we do find species of Ceratops and of Triceratops coexisting in the same beds as in the Arapahoe formation of Colorado which, although of post-Laramie age, is probably older than the Lance formation. Dr. Hay's remarks[2] on the Ceratopsia are interesting in this connection. He says:

> Apparently nine species are known from the Judith River deposits of Montana and British America; and about fifteen species are credited to the Lance Creek beds of Wyoming, and to the Arapahoe and the Denver, of Colorado. Hatcher and Lull conclude that those of the Judith epoch are somewhat more primitive than those of the beds higher up, being somewhat smaller, with a less completely developed nuchal frill, with the nasal horn relatively larger and the supraorbital horns relatively smaller than in the younger forms. It is, however, to be noted that the nasal horn of Ceratops, of the Judith River epoch, is not yet certainly known. For the most part the genera are based on the characters mentioned above. They may have the importance assigned to them, but they do not indicate radical differences. Such differences might easily have arisen during an interval of moderate duration.

The supposed primitive nature of the Ceratopsidae of the Judith River basin of Montana as compared with those of the Lance formation of Wyoming and the supposed stratigraphic positions of the beds are apparently the main reliances of the advocates for the earlier age of the former and have led to considerable confusion in their consideration by different writers. Mr. R. S. Lull[3] has thus been led astray in his phylogeny of the Ceratopsia, which is based apparently more upon supposed geological position, than upon the phylogenetic characters. He is evidently misled because

[1] *Contributions to Canadian Paleontology*, III (1902), 20.

[2] Hay, *op. cit.*, p. 24.

[3] Advance print *Proc. 7th I. Z. C.*, Boston, 1902, Cambridge, 1910, p. 2.

of his belief that two thousand feet of marine shales and sandstone of Bearpaw and Fox Hills age intervene between the Judith River beds and the Laramie [Lance] formation. These deposits, in his opinion, represent a period of subsidence during which the advancing sea drove the land animals to the west and north. He says:[1]

> Of these creatures which link the Judith River and Laramie [Lance] faunas, no remains have thus far been found so that we have no record of the evolution which must have occurred during the period of subsidence. At the close of the Fox Hills epoch, conditions much like those of the Judith River times again prevailed, and the horned dinosaurs, among other forms, sought their ancestral haunts. Four genera of Laramie [Lance] Ceratopsia are known, ranging themselves into two races or phyla which underwent a parallel evolution.

In this connection my friend Mr. J. W. Gidley of the U.S. National Museum has kindly prepared for me the following statement:

> Regarding the validity of the Ceratopsia phyla as worked out by R. S. Lull, it seems to me to be highly conjectural and not founded on a basis of valid reasoning. While it may be conceded that Ceratops is in general more primitive genus than Triceratops, it is highly improbable that, having already developed a far greater nasal horn than in any species of the latter genus, this horn should have become atrophied while the brow horns were being developed to become the principal ones. Only that Ceratops is supposed to have come from much older beds, it would be just as reasonable to suppose that the reverse might have been the case, and so far as the horns alone are concerned Ceratops might just as well have been the descendant of a Triceratops form. It seems far more reasonable to suppose that, whether contemporaneous or separated by a long time interval, Ceratops and Triceratops represent two quite distinct phyla, developing horns along different lines.

As already intimated, the principal cause of confusion is to be found in erroneous ideas as to the stratigraphic position of the beds from which the collections were made. As a matter of fact, however, the time has not yet arrived when the phyla can be correctly constructed. Not only is the material already in hand too fragmentary, but it is too meager in the number of forms supposedly identified, nor are there sufficient specimens of each species to determine the distinctions due to individual variation or to differences in sex or age. When we find that Ceratops and Triceratops (one of which is supposed to be ancestral to the other) were con-

[1] *Ibid.*, p. 4.

temporaneous in Arapahoe time, and it is stated that the affinities of *Monoclonius* are with *Triceratops* and that *Ceratops montanus* is the ancestor of *Torosaurus*, while there is a possibility that *Monoclonius* may yet be identified with *Ceratops*, the present unavoidable confusion becomes noticeably evident.

Rearranging Lull's table of the "Geological Sequence of the Ceratopsia"[1] to accord with the views set forth in this paper, we have the following:

Formations	Localities	Species
Lance	Hell Creek, Mont.	Triceratops sp. Triceratops brevicornus Triceratops serratus
Lance	Converse Co., Wyo.	Trosaurus latus Trosaurus gladius Diceratops hatcheri Triceratops brevicornus Triceratops flabellatus Triceratops calicornis Triceratops sulcatus Triceratops prorsus Triceratops horridus Triceratops elatus Triceratops obtusus
Lance	Near Judith, Mont.	Ceratops montanus Ceratops paucidens Ceratops recurvicornis Monoclonius sphenocerus Monoclonius crassus
Denver	Denver, Colo.	Triceratops alticornis Triceratops horridus
Arapahoe	Near Denver, Colo.	Triceratops alticornis Triceratops galeus Ceratops montanus*
Post-Laramie	Black Buttes, Wyo.	Agathaumus sylvestris
Laramie	Black Buttes, Wyo.	No Ceratopsia
Fox Hills	Black Buttes, Wyo.	No Ceratopsia
Pierre	Black Buttes, Wyo.	No Ceratopsia

* The type specimen of *Ceratops montanus* is in the collection of the U.S. National Museum. As to the specimen from Colorado, Professor Lull thinks "it must be a case of mistaken identity." This, in the writer's opinion, is due to the fact that the Judith River beds and those of the Lance formation are mistakenly supposed to be separated by thousands of feet of beds.

The principal differences between this table and Lull's is the taking-away of the Lance formation from the Laramie; the inter-

[1] Lull, *op. cit.*, p. 184.

polation of the true Laramie between the Fox Hills and the Black Buttes beds, which are referred by us to the post-Laramie; and the placing of the Arapahoe and Denver below the Lance, reversing the position given them by Lull and the reference also of the Judith River beds to the Lance. This arrangement appears to me not only the true one but far better, as it ties the species together in a more logical manner. It will not be necessary to conclude as Lull has that the "identification of *Ceratops montanus* seems hardly possible, as *Ceratops montanus* is a Judith River type and is vastly older than the Arapahoe." Although the Arapahoe and Denver lie at the bottom of the series and the Hell Creek beds nearer the middle or at the top of the Lance formation, we do not yet know their exact equivalency, but that they are not separated by thousands of feet of beds can confidently be stated. Mr. Cross, long ago, pointed out "the fact that the Judith River strata may perhaps represent the Arapahoe or some other post-Laramie formation."[1]

Eliminating from Hatcher's list of Judith River vertebrates (which includes no mammals in the type region) all the species which are duplicated under other names and all which come from beds not of Judith age or that occur outside the typical area (the Judith basin of Montana), his list is reduced to 33. Of these we find that 22 occur also in strata referrred to the Lance formation. These species are tabulated below. Besides the Converse County, Wyo., and Hell Creek, Mont., lists, others might be given showing that Judith River species occur in other parts of Montana as well as in northeastern Colorado, but the lists given here are deemed sufficient to prove the identity of the beds.

Writing in 1902 (and the list was not so great then as now) on the identity of genera and species not only between these beds but including also the Belly River of Canada, Williston says:[2]

> It would seem almost incredible that so many of these should have persisted unchanged through the long interval represented by so many thousand feet of Fox Hills deposits, to say nothing of those of the Fort Pierre. I doubt if a parallel can be found elsewhere in vertebrate paleontology. It is true that many of these forms from both the Judith River and the Laramie [Lance]

[1] *Monograph U.S. Geol. Surv.*, XXVII (1896), 239.

[2] *Science*, N.S., XVI (December 12, 1902), 953.

are known only from fragmentary remains and that future researches may show specific differences in some of them, but the resemblance in any event is marvelous.

This resemblance is no longer marvelous, when we know that in both cases we are talking of beds of the same age.

Judith River Formation		Lance Formation
Judith River Basin, Montana	Converse County, Wyoming	Hell Creek, Montana
Lepidotus occidentalis	Lepidotus occidentalis	Lepidotus occidentalis
Myledaphus bipartitus	Myledaphus bipartitus	
Accipenser albertensis	Accipenser albertensis	
Diphyodus longirostris	Diphyodus longirostris	Diphyodus sp.?
Scapherpeton tectum	Scapherpeton tectum	Scapherpeton tectum
Ischyrotherium, cf. antiquum	Ischyrotherium, cf. antiquum	
Trionyx foveatus	Trionyx foveatus	Trionyx foveatus
Adocus lineolatus	Adocus lineolatus	Adocus lineolatus
Compsemys obscurus	Compsemys obscurus	Compsemys obscurus
Compsemys victus	Compsemys victus	Compsemys victus
Champsosaurus	Champsosaurus humilis	Champsemys
Crocodilus humilis	Crocodilus humilis	Crocodilus sp.
Troodon formosus	Troodon formosus	
Deinodon horridus	Deinodon horridus	
Aublysodon mirandus	Aublysodon mirandus	
Paronychodon lacustris	Paronychodon lacustris	
Zaphalis abradus	Zaphalis abradus	
Deinodon explanatus	Deinodon explanatus	
Deinodon cristatus	Deinodon cristatus	
Deinodon hazenianus	Deinodon hazenianus	
Ornithomimus altus		Ornithomimus altus
Palaeoscincus costatus	Palaeoscincus costatus	Palaeoscincus sp.
Trachodon mirabilis	Trachodon mirabilis*	Trachodon sp.

* Hatcher, *Annals of the Carnegie Museum*, I, No. 3, p. 382.

In what has been written above the endeavor has been to prove from the words of the vertebrate paleontologists themselves the identity of the Judith River and Lance formations. Knocking from beneath the structure so elaborately reared the weak and ineffective stratigraphic props, the entire edifice must fall. Either the beds are identical in age, or vertebrate paleontology has no place in stratigraphic geology, and *non geologia sine paleontologia* becomes *non paleontologia sine geologia*. That they are, however, of the same age is the irresistible conclusion to which we come. Whether they are of Cretaceous or Tertiary age is beside the question at this place, although the views and opinions of the writer as to their early Eocene Tertiary age have been expressed in another part of this paper.

SUMMARY AND CONCLUSIONS

The Judith River formation was named and considered by Dr. F. V. Hayden to be of Tertiary age and, from that time (1855) to 1903, every geologist who studied the beds coincided in the main with his views. A list of these geologists who studied the beds in the field is as follows: F. B. Meek, E. D. Cope, C. A. White, Walter H. Weed, L. F. Ward, George M. Dawson, G. B. Grinnell, Ed. S. Dana, and T. W. Stanton. Not until 1903 was there any question as to their position nor much discussion as to their age, except by the vertebrate paleontologists. In this year after a study in the folded and faulted region surrounding the Bearpaw Mountains in Montana, Stanton and Hatcher traced the outcrops noted near Havre on the northeast side of the mountains up Milk River, across the international boundary to Pakowki Coulee and correctly correlated the beds exposed at Havre with the Belly River beds already identified on Milk River by the Canadian geologists, but they incorrectly correlated these beds with the Judith River formation exposed mainly between the Bearpaw Mountains and the Missouri River, confusing the two formations as the Canadian geologist had previously done. These formations were the Judith River beds overlying the Pierre and the Belly River series lying below the Pierre shales. This confusion as to position, as noted, had occurred also in the Canadian outcrops and was straightened out by McConnell and Tyrrell. Stanton and Hatcher were led into the same error also on Fish Creek south of the Musselshell River and on Willow Creek north of the same river in Montana, as was very evident to us when we revisited this area in 1911. Our first conclusion, therefore, is that the Judith River beds and the Belly River series, although both of fresh-water origin and lithologically very similar, are entirely distinct from each other, occupying stratigraphical positions separated by 1,000 feet or more of marine sandstones and shales.

The sandstones and sandy shales immediately underlying the typical Judith River beds are of marine origin and contain a fauna which Dr. Stanton says has long been considered a "typical Fox Hills" fauna. In addition to this fauna we found *Halymenites major*, a characteristic plant of the Fox Hills formation, throughout

the Rocky Mountain region. Further, a comparison of the Fox Hills fauna from the Judith River Basin with those of other sections in the Rocky Mountains, particularly with those from Colorado where the most complete Fox Hills sections is found, shows that only 4 of the 18 species occurring in the Judith River section are not found elsewhere. These Fox Hills beds in the Judith River basin were named Claggett by Dr. Stanton, but apparently this is only another name for the Fox Hills formation as developed in the disturbed portions of the Judith basin. Our second conclusion, therefore, is that the Fox Hills formation, with its characteristic fauna and flora, immediately and unconformably underlies the Judith River beds and that it rests conformably upon exposures of characteristic Pierre shales throughout the Judith basin.

It has further been shown that the Judith River beds occupy the identical stratigraphical position of the Lance formation. Both rest unconformably upon Fox Hills sandstones. Possibly we have in the Judith River beds the equivalent of only the lowest portions of the Lance formation. It has also been shown that out of 33 species of vertebrates occurring in the Judith River beds, 23 are common to both the Judith River and the Lance formations. The invertebrates of both are mainly fresh-water forms which closely resemble each other in the two formations, and the plants of both, so far as they are known, suggest a Lance or Fort Union rather than the Belly River age. Undoubtedly there are areas on all sides of the Bearpaw Mountains in which, when we get beyond the area of disturbance due to the uplift, continuous sections will show below the Pierre shales, the Belly River series with characteristic floras, and above, the Judith River beds with floras referable to the Lance and Fort Union formations. There are indications that the conditions are like those found on the Canadian side of the international boundary. We have no hesitation in stating the third conclusion, viz., that the Judith River formation is the representative if not the exact equivalent of the whole or of some, perhaps lower, portion of the Lance formation and that the latter name should be replaced on the ground of priority of use by the name Judith River formation.

We have also seen that the Belly River series is always overlain by the Pierre shales not only in the Canadian sections but also

south of the international boundary, especially in Fish Creek south of the Musselshell River, and at Willow Creek 12 miles north of Musselshell. By no stretch of the imagination, can the beds below the Belly River series be taken to represent the Pierre shales, either lithologically or paleobotanically. In both the United States and Canada, the affinities of the flora are with the Dakota and not with the Montana. The faunas, in Canada especially, show a mingling of Niobrara and Pierre forms, and although there is a bare possibility that the upper part of the Belly River series may be of basal Montana age, it is more than likely that there is here simply a mingling of forms as at the base of the Fox Hills formation, where there is a mingling of Pierre forms in the transition from one formation to the other. We are therefore fully warranted in concluding, as pointed out by Dawson long ago, that the Belly River series is of Niobrara age. The Eagle formation as named by Walter H. Weed includes about 200 feet of fresh-water sandstones overlying the leaden grey marine shales of the Colorado formation. In the sandstones plants occur that are similar to those found in the Canadian Belly River, which Dr. Knowlton afterward correlated with the Dunvegan group of Dr. Dawson as found in Canada. Dr. Stanton afterward added to the formation about a hundred feet of sandstones, shales, and lignitiferous beds from the upper part of which he says he collected marine invertebrates that showed a closer relation to the Montana than to the Colorado group. There is a possibility that some of the beds may have been wrongly identified; as Dr. Stanton says, "the formation has often been confused with several other horizons." However, the Eagle as originally defined, together with some of the immediately underlying calcareous and gypsiferous shales, marks the base of the Niobrara formation as indicated by the flora of the sandstones.

Apparently the entire series from the base of the Eagle sandstone to the base of the Pierre shales is a unit representing the Canadian Belly River formation, but it may be advisable to restrict the name Belly River to the soft badland shales at the summit and retain the name Eagle for the basal sandstones and their overlying shaly beds and possibly apply some other name (not Claggett) to the intervening beds.

USE OF SYMBOLS IN EXPRESSING THE QUANTITATIVE CLASSIFICATION OF IGNEOUS ROCKS

WHITMAN CROSS

In a recent publication F. W. Clarke[1] has given, among various geochemical data, a new average for the existing chemical analyses of igneous rocks of the world, together with other averages for continents, countries, or districts. Clarke also gives a table, prepared by Iddings, showing by names and symbols the quantitative classification of magmas corresponding in composition to those averages. Speaking of these averages as representing magmas or rocks, it is a fact, of no special significance in itself, that many of them chance to fall very near boundary lines of several divisions of the quantitative system. Consequently the simple names and symbols of Clarke's table fail to show satisfactorily the true systematic relations of such rocks. These relations may, however, be very clearly expressed by means of the elaborated symbols, proposed since the publication of Clarke's paper, by the authors of the quantitative system.[2] The efficacy of these symbols in expressing certain relations may be illustrated by showing their application to the averages of Clarke.

As the basis for the calculations to follow and to further disseminate the interesting averages made by Clarke, they are repeated in the accompanying table. Water and several rare or unimportant constituents have been omitted by Clarke and the remainders calculated to 100 per cent. The capital letters by which Clarke designates individual averages in his tables have been retained.

The normative ratios of the table on p. 760 give the data by which rocks of these average compositions may be accurately classified in the quantitative system. From these ratios the elabo-

[1] "Some Geochemical Statistics," *Proc. Am. Phil. Soc.*, XLI (1912), 214–34.

[2] W. Cross, J. P. Iddings, L. V. Pirsson, and H. S. Washington, "Modifications of the Quantitative System of Classification of Igneous Rocks," *Jour. Geol.*, XX (1912), 550–61.

AVERAGES OF CHEMICAL ANALYSES OF ROCKS, CLARKE

	A	B	C	E	F	G	H	I	J	L	M	N	O	P	Q
SiO_2	61.13	60.49	58.83	61.68	59.16	61.22	62.87	62.20	61.47	60.84	58.83	60.18	59.89	61.13	60.76
Al_2O_3	15.03	15.81	15.97	15.41	15.17	16.35	16.66	15.87	15.63	16.70	15.76	15.88	16.07	16.29	15.87
Fe_2O_3	3.50	4.90	3.36	2.67	2.16	3.30	2.67	2.12	2.67	3.75	3.96	3.90	4.18	3.76	3.40
FeO	4.38	2.77	3.91	3.55	5.36	2.58	2.40	3.46	3.22	2.68	3.75	3.44	3.18	2.93	3.19
MgO	2.86	3.81	3.88	3.97	4.92	3.47	2.06	3.93	4.02	2.10	4.09	2.82	3.59	3.18	3.78
CaO	4.81	4.95	5.27	5.02	5.69	4.95	4.01	6.06	5.12	4.39	5.73	5.83	5.30	5.54	5.23
Na_2O	3.75	3.26	3.95	3.49	3.46	3.83	4.11	3.49	3.62	4.98	3.74	3.36	3.70	4.01	3.67
K_2O	3.32	2.84	3.19	3.07	2.76	3.22	4.10	1.92	3.06	3.68	3.18	4.17	3.25	2.16	3.08
TiO_2	0.78	0.53	1.05	0.77	0.98	0.69	0.74	0.58	0.81	0.63	0.67	0.10	0.51	0.66	0.67
P_2O_5	0.25	0.22	0.37	0.27	0.23	0.31	0.27	0.27	0.27	0.14	0.22	0.21	0.20	0.14	0.23
MnO	0.19	0.42	0.22	0.10	0.11	0.08	0.11	0.10	0.11	0.11	0.07	0.11	0.13	0.20	0.12
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NORMS OF AVERAGE ANALYSES

	A	B	C	E	F	G	H	I	J	L	M	N	O	P	Q
Q	12.60	15.06	7.74	13.50	8.16	12.24	12.60	16.26	12.60	7.20	7.80	9.48	10.38	13.98	11.94
or	19.46	16.68	18.90	18.35	16.68	18.90	24.46	11.12	18.35	21.68	18.90	25.02	19.46	12.79	18.35
ab	31.96	27.77	33.54	29.34	29.34	32.49	34.58	29.34	30.39	41.92	31.96	28.30	31.44	34.06	30.92
an	14.18	20.02	16.40	17.24	17.51	17.79	15.01	22.24	17.24	12.51	16.68	15.85	17.51	20.02	17.79
di	6.55	2.62	5.78	4.67	7.60	3.95	2.44	4.91	5.96	6.83	8.40	9.64	5.94	5.28	5.30
hy	8.00	9.32	9.84	10.97	15.38	7.76	4.99	11.27	9.55	2.90	8.85	5.52	7.77	6.86	8.91
mt	5.10	7.19	4.87	3.71	3.02	4.87	3.71	3.02	3.71	5.34	5.57	5.57	6.26	5.34	4.87
il	1.52	0.91	2.13	1.52	1.82	1.44	1.52	1.06	1.52	1.22	1.37	0.15	0.91	1.37	1.37
ap	0.57	0.50	0.91	0.67	0.54	0.70	0.67	0.67	0.67	0.34	0.50	0.50	0.50	0.34	0.54
	99.94	100.07	100.11	99.97	100.05	100.14	99.98	99.89	99.99	99.94	100.03	100.03	100.17	100.04	99.99

A. Average of 248 "superior" analyses of igneous rocks selected by Washington from Roth's tables. See *U.S. Geol. Survey, Prof. Paper No. 28.* Computed by Clarke.
B. Average of 536 British rocks, computed by Harker. "Tertiary Igneous Rocks of the Isle of Skye," *Mem. Geol. Survey, United Kingdom*, 1904, p. 416.
C. Washington's average of 1,811 rocks from all parts of the world. *U.S. Geol. Survey., Prof. Paper No. 14*, p. 106.
E. Average of all data relating to the composition of igneous rocks contained in the laboratory records of the U.S. Geol. Survey (Clarke).
F. Average of 250 analyses of rocks from the Atlantic slope, Maine to Georgia.
G. Average of 113 analyses of rocks from Yellowstone Park.
H. Average of 137 analyses of rocks from Colorado.
I. Average of 105 analyses of rocks from California.
J. Average for all North America. E combined with 398 analyses from Washington's tables.
L. Average of 231 analyses of rocks from Norway, Sweden, and Finland.
M. Average of 420 analyses of rocks from Germany and Austro-Hungary.
N. Average of 250 analyses of Italian rocks.
O. Mean of 1,437 analyses included in B, L, M, and N, plus 122 other analyses of European rocks.
P. Average of 82 analyses of rocks from South America.
Q. General mean of all analyses considered by Clarke.

rated symbols may also be readily determined. Referring to the original paper, already cited, for details of the new proposition, it may be briefly explained in this place.

It is recognized that it is desirable to express in the quantitative system two frequently observed relations of rocks which cannot be shown by the simple magmatic name or the symbol hitherto used. Two rocks often fall in opposite extreme portions of a division, while two others may be found occurring in two adjacent divisions but very near the boundary line. It has been proposed to establish *intermediate* and *transition* zones, the former extending

TABLE OF NORMATIVE RATIOS

	Class $\frac{Sal}{Fem}$	Order $\frac{Q}{F}$	Rang $\frac{K_2O'+Na_2O'}{CaO'}$	Subrang $\frac{K_2O'}{Na_2O'}$
A	3.59	0.19	1.88	0.57
B	3.87	0.23+	1.15	0.57
C	3.25	0.11	1.661	0.53
E	3.64	0.21	1.43	0.59
F	2.53	0.13	1.36	0.54
G	4.36	0.176	1.50	0.55
H	6.50	0.17	2.04	0.67
I	3.77	0.26	0.95	0.36
J	3.67	0.19	1.47	0.57
L	5.01	0.09	2.64	0.49
M	3.06	0.11	1.58	0.56
N	3.67	0.137	1.74	0.83
O	3.68	0.15	1.51	0.58
P	4.21	0.21	1.22	0.35
Q	3.76	0.178	1.44	0.56

on each side of a given division line one-half the distance to the center points of adjacent divisions and the latter one-fourth of this distance. The boundaries of both intermediate and transition zones are determined accurately by the ratios of the two quantities concerned in the formation of classes, orders, etc. These determining ratios are given in the cited publication.

The transitional position of a rock may be expressed by a compound name, but where it is transitional in more than one respect, as frequently happens, it is desirable to use only the two subrang names expressing the lowest systematic stage in which such transitional relation exists. This usage is illustrated in the following table. In the symbols the transitional relation is indicated by giving in parentheses, beside the number of the division in which

a given rock falls, also the number of the division toward which it is transitional.

The intermediate position of a rock is expressed by prime marks placed either before or after the number of a division according to the direction in which the rock is intermediate.

The result of applying these devices to the quantitative classification of Clarke's average rocks is shown in the accompanying table. It appears at once from the symbols of this table that all but three of the average rocks fall in the central half of Class II; that the three exceptions are intermediate to Class I, and that one is within the transitional bounds. The ratios show that not one of these rocks is half-way from the center point of Class II toward Class III.

QUANTITATIVE CLASSIFICATION OF AVERAGE ROCKS

Average of Analyses	Name	Class $\frac{Sal}{Fem}$	Order $\frac{Q}{F}$	Rang $\frac{Alkalies}{CaO'}$	Sub-rang $\frac{K_2O'}{Na_2O'}$
H 137 rocks of Colorado....	Dacose-adamellose	(I) II	4(5)	2′	3(4)
A 248 analyses, Roth's tables	Adamellose-dacose	II	4′	2(3)	(3)4
G 113 rocks of Yellowstone Park.....	Harzose-tonalose	′II	4(5)	(2)3	(3)4
J North America.....	Harzose-tonalose	II	4′	(2)3	(3)4
E U.S.G.S. analyses.....	Harzose-tonalose	II	4′	′3	(3)4
B 536 British rocks, Harker	Harzose-tonalose	II	4	3	(3)4
O 1659 rocks, Europe.....	Harzose-tonalose	II	4(5)	(2)3	(3)4
Q World's average, Clarke..	Harzose-tonalose	II	4(5)	′3	(3)4
I 195 rocks of California...	Tonalose	II	4	3	4
P 82 rocks of South America	Tonalose	II	4′	3	4
N 250 rocks of Italy.....	Shoshonose-monzonose	II	(4)5	2(3)	3
M 420 rocks of Germany and Austria.....	Shoshonose-andose	II	(4)5	(2)3	(3)4
F 250 rocks of Atlantic Coast, U.S.....	Shoshonose-andose	II	(4)5	′3	(3)4
C World's average, Washington.....	Monzonose-akerose	II	(4)5	2(3)	(3)4
L 231 rocks of northern Europe.....	Akerose	′II	′5	2	′4

With regard to the relation of normative quartz and feldspar, determining the order, it is seen that eight rocks fall within the narrow transitional limits between Orders 4 and 5, half of them on one side and half on the other. Of the remainder all but two are intermediate toward the same boundary line. Of the two rocks coming within the central half of Order 4, B and I, the former is

almost on the intermediate line. The extreme range from I to L is less than one-half that of Order 4.

In regard to rang, expressing the quantitative relation of alkalic to calcic feldspars, the new symbols further emphasize the relationship of most of these averages. The range from the most alkalic rock, L, to the most calcic, I, is somewhat less than that of a full rang.

In the relation of potassic to sodic feldspars, a large majority are found to be transitional between dosodic and sodipotassic subrangs, although but two are of the latter. The average of Italian analyses would represent a sodipotassic magma, but even in this case falling on the sodic side of the centerpoint of Subrang 3. The next most richly potassic average is that of Colorado analyses, but it is to be noted with regard to this average that a large number of analyses of phonolite and other sodic rocks from the small Cripple Creek center somewhat obscure the characteristic relative abundance of potash which the writer has long recognized in Colorado rocks.

The use of these new symbols by the writer has convinced him that they afford a good means of expressing in a concise way close relationships or marked differences which it is otherwise necessary to explain in many words. It is to be hoped that petrographers using the quantitative system may become impressed by the status of the transitional rock. It is just as important as any other type, but unless the transitional character is expressed by name or symbol, erroneous impressions may be given. A rock specimen shown by analysis to occupy a transitional position may have come from a mass which as a whole belongs on the opposite side of the division line. It is evident that special care is desirable in the calculation of the norm and the ratios of transitional rocks.

In closing, it seems well to point out to petrographers that it is bad practice to name any division of the quantitative system after the occurrence of a type which is transitional in any respect. The authors of that system have themselves erred in a few cases, but some subrang names recently proposed by other petrographers are particularly unfortunate. It would be well in future, in the writer's opinion, to base a name only on a type falling within the central half of each division of the system.

THE PHYSICAL SETTING OF THE CHILEAN BORATE DEPOSITS

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North of the Tropic of Capricorn, the Andes of Chile and Bolivia stand forth as two massive chains with a lofty plateau between. The two great ranges of Andes are known as the Cordillera Occidental and the Cordillera Oriental, or Cordillera Real. The lofty tableland between passes under the name of Altaplanicie, or Great Central Plateau of Bolivia. It is in some respects one of the most remarkable topographic features of South America. Throughout nearly ten degrees of latitude its surface maintains an elevation of approximately 12,000–13,000 feet above sea-level. But apart from its greater elevation this broad inter-Andine tableland shows a resemblance to portions of the great basin region in the western United States.

This plateau is boxed in on the east by the great wall-like ridge of the Eastern Cordillera which culminates in the giant peaks of Illimani (21,200 feet) and Illampu (21,490 feet). On the west the plateau is bounded by a remarkable string of volcanoes which constitute the Western Cordillera. The two systems of mountains are totally unlike. While the eastern range, or Cordillera Real, is composed of folded Paleozoics, with the still older granites and gneisses exposed in the axis of the range, the Western Cordillera is conspicuous chiefly as a chain of volcanic cones perched upon the western edge of the great plateau. These volcanic cones rest upon folded Mesozoic strata, chiefly of Jurassic and Cretaceous age. The body of the plateau itself is composed principally of beds ranging in age from the Devonian to the Cretaceous.

Throughout the extent of the plateau, in Chile, Bolivia, and Peru, are numerous lakes, saline marshes, and beds of former lakes, most of which possess no outward drainage. The large bodies of water which still persist, like Lake Titicaca and Lake

Pampa Aullagas, are well enough known, but in addition there are many minor lake flats, dry or nearly so, which escape notice. It is on some of these old lake bottoms that the great borate deposits of South America occur. But here the geographic distribution of the lakes which contain borax is of significance, as it is found that the deposits of borax are largely confined to those lakes which lie close to the volcanoes of the Western Cordillera. Away from the volcanoes, whether eastward over the central plateau, or westward down the long desert slopes leading toward the coast where the nitrate beds abound, the borates rapidly disappear. The borates thus seem to be related to the volcanoes. The nitrates occur on open salinas at moderate elevations, 3,000–5,000 feet, and not far back from the coast. The borax fields, on the other hand, are located high up on the edge of the tableland close to the base of the big volcanoes. Both nitrates and borates are dependent for their accumulation and preservation upon the extreme aridity of the region, but the sources of the nitrogen and the boron are quite different.

The Salinas of Ascotan may be taken as a typical case to show the probable source of the borates. The railroad from Antofagasta to Bolivia creeps steadily upward from the coast and reaches its highest point in crossing the Western Cordillera at the station of Ascotan, which is about 13,000 feet above the sea. The Western Cordillera here consists of volcanoes most of which have only recently become extinct, while, from a few, smoke is still escaping. In the neighborhood of Ascotan the cones rise to heights of 17,000–19,500 feet. But in spite of the great altitude only an occasional patch of snow is seen on these lofty peaks owing to the extremely scanty precipitation, for this region lies at the northern end of the desert of Atacama.

After climbing up to Ascotan the railway runs parallel to the line of volcanoes and the great borax lake of Ascotan comes into view. This lake is perhaps 10 miles long and 3 miles wide, extending northward parallel to the range to a point beyond Cellobar. It fringes the base of a line of volcanoes which begin at the south in the cone of San Pedro y Pablo (19,400 feet) and end north of the lake in the smoking volcano of Ollagüe (19,200 feet). The

slopes of the volcanic cones rise directly from the shores of the borate lake. In the so-called lake very little water is seen; most of its surface is a white field of borate which rests upon the watery mass below like ice upon a partially frozen pond. It is really a borate incrusted lake bed.

The craters of the adjoining volcanoes are all quite recent, and some of them are probably dormant rather than extinct. Ollagüe at least still emits a thin thread of smoke from an orifice in its upper slopes. Drainage lines are not yet well established,

FIG. 1.—Volcano on border of Ascotan Borax Lake. The drainage from the crater passes directly into the lake.

but whatever drainage and seepage there may be from these cinder cones would necessarily pass, in large part, directly into this lake basin. Underground drainage from several large volcanoes would find its way into the borax lake. One of the craters was seen to have its wall broken down on the side toward the lake so that much of the surface runoff from the crater walls as well as the underground seepage through the cinder cone would go directly to the lake (Fig. 1).

The lake has no apparent outlet so that the small amount of water on the lake bed represents a state of balance between the

scanty precipitation which falls upon the basin and its volcanic borders, and the loss by evaporation. Necessarily there is a concentration of salts as evaporation goes on. All salts dissolved by waters which trickled through the volcanic cones and reached the lake flat would gradually become concentrated there as the water evaporated and would finally be deposited as a solid incrustation.

The water entering the lake, whether directly or by the underground route, can have come in contact with little besides volcanic material, since all the higher land around the lake is made up of volcanic rocks. Therefore the source of the boron is to be sought in the volcanoes. Unfortunately lack of time did not permit an examination of the craters themselves. But it is known that borates and free boric acid in the form of sublimates from hot vapors are often conspicuous deposits around fumaroles and active volcanic craters in various other parts of the world. Judd states that in the solfataras of Tuscany, boracic acid is, next to the true gases, the most noteworthy compound emitted from the vents.[1] Vulcano, in the Lipari Islands, emits boracic acid which, attacking the materials of the surrounding rocks, has formed borates of the alkalies and alkaline earths.[2] These new chemical compounds are continually accumulating on the sides and lips of fissures from which the acid gases and vapors are issuing. The mineral sassolite ($B_2O_3 . 3H_2O$) is common at Vesuvius.[3] Compounds of boron are therefore to be expected in these Chilean volcanoes and it may be supposed that rain-water falling upon these craters and percolating through the cinder cones would dissolve the soluble boron salts and later deposit them on the lake bed where the water finally evaporated.

But in addition to borates, other salts soluble in water, such as chlorides, sulphates, etc., are also present in volcanic craters. These should also be dissolved by rain-water and carried down onto the evaporating flat as well as the borates. This has evidently happened in the Ascotan field, for the percentage of borate varies

[1] J. W. Judd, *Volcanoes*, p. 216.

[2] *Ibid.*, pp. 42–44.

[3] J. L. Lobley, *Mount Vesuvius*, p. 321.

considerably in different parts of the area. The boron, however, occurs almost entirely as a single compound, the mineral ulexite, or boronatrocalcite ($NaCaB_5O_9.8H_2O$). But there would seem to be in operation some process by which the various salts derived from the volcanoes are separated before being deposited on the lake flats, for in some parts of the field the boronatrocalcite occurs remarkably pure. It is in such places that it is now being worked for borax. The material is so free from other salts that it is only

FIG. 2.—Borax incrusted lake flat with the volcano Ollagüe in the distance. Other volcanic peaks to the right.

necessary to dry it before shipping it to Europe, where it is later refined. But in other parts of the region the borate occurs in beds alternating with layers of salt and salty earth with some glauberite and gypsum associated.

Some distance beyond Cellobar is another dazzling white bed of borax whose flatness the railroad to Bolivia utilizes by running straight across it. Close by is the big volcano Ollagüe which is still smoking (Fig. 2). On other sides the borax flat is hemmed

in by several scarcely less massive cones which would seem to provide ample sources for the borate in the basin.

Beyond the station of Ollagüe the train, turning more to the east, leaves the volcanic Cordillera and makes its way over the Great Central Plateau to Uyuni and Oruro. This region is a great detritus-strewn plain with low ridges and ranges trending generally north and south. Salt marshes and old lake beds continue, but as the volcanoes are left behind, the deposits of borax rapidly disappear. There are no known borate deposits associated with the non-volcanic Eastern Cordillera.

WATER-WORN COAL PEBBLES IN CARBONIFEROUS SANDSTONE

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Geological Survey of Alabama

The accompanying photograph illustrates rounded pebbles of bituminous coal, one of which is shown imbedded in a coarse-grained sandstone. These pebbles are exposed in large numbers in a stone quarry which is located[1] on the banks of the Warrior River just above Lock No. 12, Tuscaloosa, Ala., and but a short distance from the State University. The sandstone is in some places very coarse and conglomeratic. In many cases the coarse fragments making the conglomerate are angular, having received but little wear. At the locality where the coal pebbles occur most numerously there is much cross-bedding of the sandstone and a marked difference in the coarseness and fineness of the sediment together with considerable contemporaneous erosion, thus giving evidence of a delta deposit. In the sandstone which carries the coal pebbles are found many fragments of carboniferous trees. The geological position of this sandstone is near the top of the coal measures of the Warrior Coal Field, being about 60 feet above the Duree coal seam and about 30 feet below the Brookwood coal seam of the Brookwood group (the highest known group of coals in the Warrior field). The size of the pebbles varies from ½-inch to 15 inches or more in diameter. One pebble observed had the shape of a prolate spheroid about 18 inches long and nearly 12 inches thick. This was imbedded in a coarse-grained sandstone.

An analysis of the coal, from the pebble shown in the photograph imbedded in the rock, is as follows:

Moisture	2.42
Volatile matter	38.73
Fixed carbon	56.06
Ash	2.79
	100.00

[1] The occurrence of coal pebbles at this locality was first called to my attention by Dr. E. A. Smith of the University of Alabama.

The above analysis shows the specimen to be a high-grade bituminous coal. Its composition is almost identical with that of the seam which lies some 60 feet below it, the Duree seam of coal which gives the following analysis:

Moisture	2.30
Volatile matter	38.58
Fixed carbon	54.11
Ash	5.01
	100.00

The origin of the pebbles is not perfectly clear. That the material forming the pebbles was water-worn before being imbedded in

FIG. 1.—Water-worn coal pebbles occurring in coarse-grained sandstone in upper measures of Warrior Coal Field, Ala. No. 2 is a portion of a pebble 8 inches in diameter.

the coarse sand and conglomerate is very evident, and that the agent of erosion was a carboniferous stream is also evident, but whether the material now forming the coal was then in the form of chunks of coal or pieces of lignite or less carbonized wood is not apparent.

It is a well-known fact that at the present time pebbles of coal are being transported and rounded by stream action, yet the question would naturally present itself as to where the carboniferous stream could get this coal, since it is not possible that the beds of coal below could furnish it without a considerable warping and erosion of the strata prior to the period of the deposition of the coal pebbles, but such warping and erosion is not known, and even

granting such to be the case it would hardly seem possible that sufficient time would have elapsed for the coal bed some 60 feet below or even for other carbonaceous deposits still lower down in the coal measures to yield more than a lignite. It would seem to me therefore that these carbonaceous pebbles were originally transported not as a coal but as chunks of lignite or wood. It seems to me also more reasonable to conclude that they were in the form of lignite rather than in a less carbonized form, since many of the pebbles are nearly spherical and not flattened as would be expected if the pebbles were formed of wood.

Occurrences of water-worn pebbles of coal in the rock are doubtless well known to many geologists, but it has not been my pleasure to see deposits with such large pebbles elsewhere.

Reviews

An Introduction to the Geology of New South Wales. By C. A. Süssmilch. Pp. 177+xii; figs. 79 and geological map. Sydney: W. A. Gullick, Government printer, 1911.

In 1909 E. F. Pittman brought out his *Epitome of the Geology of New South Wales*, which was welcomed by the geological world as giving in brief space an outline of the geologic history, so far as then known, of that interesting but far-away state. Now we are favored with a fuller and most excellent treatment of the geologic record in detail.

The earliest geologic formations in New South Wales are of limited extent. The oldest fauna yet found is the pelagic Ordovician graptolite fauna which is very poor in other forms. But in the Silurian, which is perhaps the most extensive outcropping formation in New South Wales, there is found a great wealth of fossils indicating conditions favorable to life. The Silurian was terminated and the Devonian inaugurated by pronounced deformative earth movements. In the littoral fauna, brachiopods predominated while trilobites are absent. Their absence is not easily explained, for trilobites flourished in the Silurian and are found in considerable numbers in the Carboniferous, indicating that they had not become extinct. The Devonian was closed by one of the greatest mountain-making epochs in New South Wales. Since then no part of the state, excepting the northeastern section, has been subjected to similar orogenic movements. The present elevation of the strata above sea-leavel is due to vertical uplift only.

A typical Permian formation, analogous to that of the Northern Hemisphere, does not occur in Australia, its place being taken by the so-called Permo-Carboniferous. This name has been applied in Australia to a thick series of marine and fresh-water beds which follow the Carboniferous as Süssmilch uses the term, and which in turn are overlain by fresh-water Triassic strata. An unconformity marks the division into Carboniferous and Permo-Carboniferous—a division which would seem to correspond approximately to the break between the Westphalian and Stephanian in Europe. Rather strangely, not a single member of the Carboniferous flora passed onward into the Permo-Carboniferous. The refrigeration of the climate which took place at

the beginning of the latter period, as indicated by the glacial beds in New South Wales and other parts of Australia, has been suggested as the cause of the marked break between the two floras.

Fresh-water formations characterize the Triassic and Jurassic, but a subsidence with an extensive marine transgression took place in Australia during the Cretaceous, somewhat as in the other continents. But in the Tertiary neither marine nor lacustrine deposits of any importance are known to occur; the geological formations fail to provide an adequate record of the history and much of what is known is inferred from the topographic features. The history ends tamely, for the Pleistocene glaciation in Australia was limited in extent.

Because of the definiteness with which the subject-matter is handled, the book will be extremely useful to students in far-away countries who need the larger features and the bearing of the essential facts brought out clearly but concisely. A chapter is given to each geologic period and each chapter closes with a well-considered summary which emphasizes the most significant features of that particular period. The treatment is judicious and philosophic.

R. T. C.

History of Geology. By HORACE B. WOODWARD. New York: Putnam, 1911. Pp. 204.

This little volume is included in "A History of the Sciences" series, and well accomplishes the purpose of printing a history of geology in small compass. On the whole the work has been well done, but the reader will sometimes be inclined to think that perspective has been lost through the prominence given to English geologists of the pre-observational period. The author's judgment is not always unerring, as for example in the place accorded to the bombastic and imaginative De Luc. The effect of De Luc's activity, as viewed from this distance, would seem to have been chiefly to stem the advance of independent thought by such men as Hutton and Playfair, and to lead the reactionary elements within the church.

W. H. H.

LOWER CRETACEOUS OF MARYLAND

Under the simple title *Lower Cretaceous*, the State Geological Survey of Maryland issues what is in effect a monograph of the Lower Cretaceous formations of the state and their paleontology. For while the work consists mainly of the descriptions of all the fossils hitherto found in

beds of that age in the state, a comprehensive though brief treatment of the stratigraphy, sediments, and geologic history of the formations furnishes more than a mere introduction and background for the paleontology. The volume combines the observations, experience, and knowledge of the three geologists, who more than anyone else have for many years been occupied with the study of these formations, William Bullock Clark, Arthur B. Bibbins, and Edward W. Berry.

In Maryland the Lower Cretaceous consists of three mutually unconformable formations, Patuxent, Arundel, and Patapsco, which collectively compose the Potomac group. For the benefit of those who may not have followed the progress of Atlantic Coastal Plain geology, it may be stated that no doubt is left as to the Cretaceous age of the oldest bed of the Potomac group. According to the conclusions of the authors the earliest Lower Cretaceous of the Atlantic coast in Maryland and Virginia was, after the long post-Newark hiatus, laid down in an old estuary or behind certain obstructive barriers. In this way they seem to compromise between the theory of California-gulf conditions of deposition proposed by McGee, on the one hand, and the absence of all types of marine life on the other. Account is, however, taken of the thinning of the beds to the eastward beneath the Tertiary overlap, as shown by drill records; of the fluviatile or lacustrine aspect of part of the Patuxent sediments; of the ancient forest soils and swamps of the Arundel; of the indications of differential warping, and of probable faulting near the "fall line." The average thickness of the Potomac in Maryland is between 600 and 700 feet and the average of the variable dips about 60 feet to the mile southeastward.

The Patuxent (lowest) formation, comprising a maximum thickness of 350 feet of cross-bedded sands and gravels, with some clays and kaolinized feldspar, is regarded as having been laid down in an estuary in a climate considerably warmer than that of today, within a region clothed with temperate rain forests, made up of a dense growth of ferns and cycads in more or less pure stands, with occasional conifers towering above the general level of the vegetation, which was relatively low, and gradually predominating in passing from the coast to the uplands. Growth rings in the petrified woods show seasonal changes, but the great width of the active growth ring and the narrowness as well as the irregularity of the zones of restricted growth suggest the occurrence of dry seasons rather than of frosty winters. It is certain that the winter cold was less than that of Maryland today. With the exception of one fish, the known Patuxent fossils are exclusively vegetal. They comprise

about 100 species, most of them either Jurassic survivors or of Jurassic aspect. About forty of the species do not survive the relatively short hiatus following the Patuxent.

The Arundel formation consisting typically of drab, more or less lignitic clays, carrying iron carbonate or siderite in segregations of varying forms, attains a maximum thickness of perhaps 125 feet in the middle of the belt in central Maryland, whence it thins to the seaward, with a general dip to the southeast of about 50 feet to the mile. This formation has not furnished a rich flora, but it is remarkable as the source of all the saurian vertebrates, including eight dinosaurs and one crocodile, discovered in the Potomac group. It has furnished also the three fresh-water gastropods and one of the two fresh-water pelecypods. The Arundel flora, numbering but 33 species, four only of which are not known in either of the contiguous formations, is botanically much more closely bound to the underlying Patuxent than to the Patapsco. The vertebrates of the Arundel point toward Morrison age which Professor Lull, in agreement with Williston and many other geologists, is disposed to regard as Cretaceous, at least in part. The flora is apparently bound to that of the Kootenai, also Cretaceous. According to Berry the base of the Kootenai, so far as the latter is known by its fossil plants, is slightly older than the base of the Patuxent. Berry and Lull accordingly agree that the Patuxent and Arundel formations are of Neocomian and Barremian age.

A considerable hiatus (Aptian) appears to have elapsed before the Patapsco formation, embracing over 200 feet of sands and clays, notably variegated argillaceous material, covered and even considerably transgressed the areas of the Patapsco and Arundel. Of fossil animals, a single species, *Unio patapscoensis*, has been found in this formation. However, the Patapsco flora is both interesting and important. The contrast of the flora, embracing 83 species, is marked not only by extinction of the earlier plants (including 17 ferns, 24 cycadophytes, 1 ginkgo, 12 other gymnosperms, and all of the 7 supposed primitive angiosperms) but also by the introduction of higher forms of distinctly younger aspect. For in addition to the 41 Patuxent-Arundel species which survived from the older formations there are found 42 new types, including many unquestionable angiosperms. It appears that during the interval between Arundel and Patapsco time the dicotyledons which were destined so soon greatly to outnumber the plants of all other classes in the upper Cretaceous floras had already made a good start.

The limit of space forbids even mention of the wealth of philosophical

botanical details regarding the development of the plant types, their relationships, associations, distribution, and so on. With the thoroughness characteristic of his method Berry not only describes all the species of fossil plants known from the lower Cretaceous in Maryland, but, as a basis for discussion and comparison, he summarizes all of the known lower Cretaceous floras of other parts of the world. The value of the latter treatment appears not only in his discussion of the age of the American plant beds, but in the broader correlations and in the historical outlining of the floras. His correlations show a refinement and precision that will surprise many who have not followed the recent studies of the Cretaceous floras of the Atlantic coastal plain. As already noted the Patuxent-Arundel flora, considered as a whole, is regarded by Berry as representing all but the lower portion of the Neocomian together with the Barremian. The Patapsco he correlates, on apparently good evidence, with the Albian, the Aptian of the old world being represented by the hiatus between the Arundel and the Patapsco. It may be noted in passing that a surprisingly large number of the previously recorded species of the Potomac formation fall into the ranks of synonomy as being in Berry's judgment not well founded.

Of the other well-known plant-bearing formations of the older Cretaceous in America, the Trinity is considered by Berry as representing the Aptian and the upper part of the Barremian. The Lacota formation, in the Black Hills, he views as transgressing lower on the Barremian and as falling short of the close of the Aptian, thus overlapping on both the Trinity and the Arundel, while the Fuson formation of the same region falls, he believes, within the Albian, though it is not so early as the basal portion of the latter. As already indicated, the Morrison-Kootenai beds he treats as probably Cretaceous, in which the Kootenai persisted to the close of the Barremian. On the California side the Knoxville-Horsetown beds are interpreted by him as reaching without break from the top of the Jurassic into the base of the Albian.

A map shows the distribution in Maryland of the Potomac group, the local stratigraphy and areal geology of considerable portions of which have previously been represented in greater detail in several folios of the U.S. Geological Survey.

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